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This study, commissioned by INVESTprojekt, Ltd. Brno, has been prepared for the Ministry of Environment of the Czech Republic by the Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam. The report has been written by an interdisciplinary project team as an extended version of project *Tyre Recycling in Europe: Open Borders in the Waste Hierarchy* conducted at the IVM/VU.

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1. Introduction

The increased number of vehicles has led to a tremendous growth in the volume of used tyres. Although used tyres represent only a limited portion of the total waste stream, in terms of volume and chemical composition, they are very important. Every year, approximately 800 million scrap tyres and 3 million tonnes of used compounded rubber products are disposed around the globe and this amount is expected to increase by 1.4% for cars and 2.2% for commercial vehicles (UNCTAD, 1996; EEA, 1995).

Improper disposal of used tyres poses negative environmental impacts and it is also a waste of valuable materials and energy. Being aware of these facts, the progressive European countries have already taken actions for environmentally sound handling of their used tyre arisings. The European Union has also expressed the approach towards sustainable waste tyre management.

In January 19998, the Czech Republic enacted a new waste legislation on the basis of EU standards. By introducing the ban on landfill and producer liability defined as take back obligation for used tyres and tyre related rubber waste, the legislation has shown an on-going environmental attitude for waste tyre management. However so far, the new legislation has not been fully implemented and the progressive policy instruments have not shown yet to be effective.

In spite of the accepted progressive legislation, the present situation in the Czech waste tyre management is far from the environmentally desired practices. Used tyres are still disposed of by landfill, recovery rate is low and a collection system is missing in the country. In this respect, an overall national waste tyre management strategy is urgently needed.

1.1 Objectives

This report prepared for the Ministry of Environment of the Czech Republic is aimed to serve as a background material for developing a national waste tyre management framework in accordance with the EU legislation and trends recognised in Europe.

The main objectives of the study are:

- Present an overview on waste tyre management pattern in Europe with a special focus on the most commonly used processing alternatives, applied policies and associated main trade flows;
- Define the economic and environmental impacts of available processing routes and identify the most socially beneficial options for waste tyre disposal in Europe;
- Provide recommendations for future activities when preparing the national waste tyre management strategy in the Czech Republic.

1.2 Report structure

- *Chapter 2* provides background information on a tyre including its composition, properties, environmental impacts and phases of entire life cycle. It also gives an overview on trends in tyre production pattern.
- *Chapter 3* describes the main world and European trade flows of used tyres and tyre related rubber waste.
- *Chapter 4* intends to give an overview of the legislation and policy frameworks within which the debate on waste tyre management is taking place focusing on international and European level.
- *Chapter 5* discusses the most common waste tyre management options, their environmental and economic aspects, current markets and their potentials in Europe.
- *Chapter 6* outlines the waste tyre management pattern in Europe including the actual statistic data on used tyre arisings, share of waste management alternatives, policy developments and industry initiatives for selected European countries.
- *Chapter 7* surveys the current situation in processing used tyres and tyre related rubber waste in the Czech Republic and the Netherlands representing Eastern and Western Europe with the aim to identify the main differences between these two scenarios.
- *Chapter 8* analyses and identifies on the basis of extended cost benefit analysis, the most promising options for processing used tyres in Europe from economic and environmental point of view.
- *Chapter 9* summarises and discusses the main conclusions from the previous chapters.
- *Chapter 10* presents the main recommendations from this study.

2. Main characteristics of tyres

2.1 Composition and properties of tyres

Tyre is a rubber article with a complicated structure. Chemical content, physical composition and properties of a tyre eventually determine the overall tyre characteristics during its whole life cycle including impacts on economic and environmental performance.

2.1.1 Chemical composition

A tyre comprises of different materials and structural components which enhance the performance and properties of the tyre. Composition varies with the size and type of a tyre. Approximately, 70% of total weight of car tyres and 65% of truck tyres is rubber compound which is combination of natural and synthetic rubber hydrocarbons. In general, truck tyres have larger natural rubber content compared to car tyres. Steel, textile and carbon black are the main reinforcement materials of tyres. The amount of steel wire used in tyres is larger for truck tyres compared to passenger car tyres. Table 2.1 presents the average material composition of new and used passenger car and truck tyres.

Table 2.1 Average composition in % of new and used passenger car and truck tyres

	Car		Truck	
Tyre materials	new	used	new	used
Rubber hydrocarbon	48	47	45	43
Carbon black	22	21.5	22	21
Steel	15	16.5	25	27
Textile	5	5.5	-	-
Zinc oxide	1.2	1	2-2.2	2
Sulphur	1	1	1	1
Others	8	7.5	6	6

Source: Information Document on Used Tyres, 1991

2.1.2 Physical composition

Depending on their application, tyres vary considerably not only in material composition, but also in type of structural components, construction and total weight. The tyre weight varies from 7 kg for a passenger car tyre to about 60 kg in average for a truck tyre. Based on the composition, tyres can meet many different requirements and demands made on tyres such as durability, economy, driving safety and others.

The basic structural components of tyres are tread strip, belt, casing, inner lining, sidewall, bead reinforcement and bead core. Appendix II provides a more detailed description of structural components and their functions. Although all components have an impact on the life of a tyre, durability of the casing directly influences the future reuse of post consumed tyres, especially in the case of retreading.

The most important classification of tyres to diagonal and radial tyres is according to the construction methods. The construction differs in the configuration of the reinforcing material. Introduction of the radial tyre concept substantially improved design and had an impact on reaching the standards and requirements made on tyres today. As a consequence, the radial tyre dominates today's passenger and truck sector in majority countries.

2.1.3 Thermal properties

The calorific value of a tyre is between 30 and 35 MJ kg^{-1} (8.3-8.5 kWh . kg^{-1}). Considering large hydrocarbon content of tyres, it is not surprising that tyres are excellent fuel providing similar calorific values commonly achieved by conventional fossil fuels. Therefore, used tyres represent an alternative to conventional fossil fuels. (For comparison of thermal properties of a tyre with other fuels see Appendix III).

2.2 Environmental impacts

The most acute environmental concern of a tyre is associated with its post consumption stage. When handled properly, a tyre does not pose significant environmental impacts. On contrary, when disposed of it may represent serious environmental and public health risks. Because tyres are resistant to natural decomposition, they cause cumulative solid waste problems which deteriorate the environment, natural beauty and scenic value of landscape.

When disposed of by landfills, tyres remain intact for decades posing potential risk for leakage of zinc, sulphur and other pollutants. In this respect, landfilled tyres are threat to soil, ground and surface water. Moreover, when whole tyres are landfilled they tend to migrate breaking the sanitary landfill cap which increases instability in disposal sites.

Tyres in landfills also pose serious fire and health risks. Major fire episodes may last for a long time, affecting the quality of air by uncontrolled releases of air pollutants. Because of their shape, landfilled tyres can collect rain water and windblown pollen which creates environment favourable for pests, rodents and mosquitoes representing health hazards, including mosquito-born diseases. Additionally, landfill of used tyres is waste of valuable materials and energy. In this respect, attention in future used tyre management should focus on alternatives to this disposal route.

When tyres are incinerated, air pollutants are emitted; however, their release can be sufficiently controlled by flue gas treatment facilities. Although scrubbers and other end-of-pipe environmental technology remove zinc oxides and up to 90 % of SO_2, incineration still produces 24 grams of CO_2 per million joules. This is the same amount emitted by a coal fired plant (EEA, 1996).

2.3 Tyre life cycle

Tyre life cycle comprises of three main phases which include production, consumption and post consumption. Since this study focuses on the last phase of a tyre life cycle, this subchapter provides only background information on tyre production and consumption which are relevant to waste management of post consumed tyres. The life cycle of a tyre is depicted in Figure 2.1.

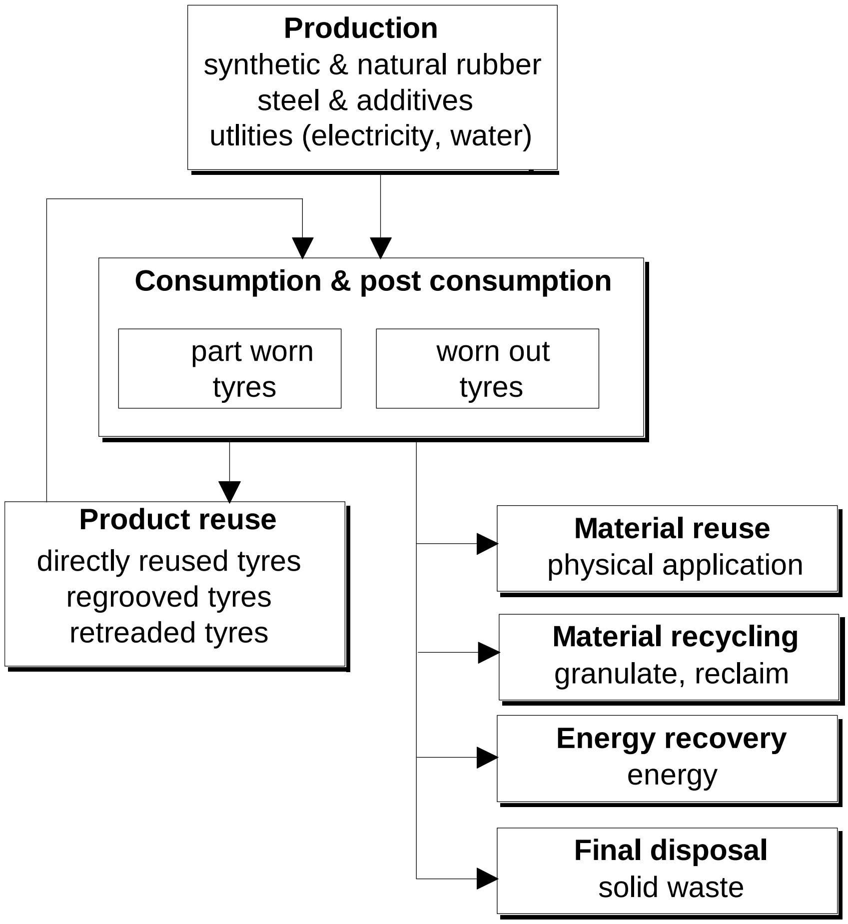

Figure 2.1 Life cycle of a tyre

2.3.1 Production

Every day more than 2 millions of tyres are produced in the world. Considering tyres are built up of many components, such as various rubber compounds, textile, steel and chemical additives, tyre production is a material and energy intensive process. Rubber compounds include natural and synthetic rubber; their ratio predefines tyre characteristics. Natural rubber comes from biomass collected from *Hevea brasiliances* (rubber tree) plantations. Synthetic elastomers are obtained from petroleum and coal taking several stages to be produced. All the input materials of a tyre are finally combined and vulcanised. Vulcanisation gives tyres their unique characteristics important for their consumption but makes further processing in post consumption phase a difficult task.

Market developments of tyres: In 1996, the major production of tyres in the global market was held by six companies: Michelin (France), Bridgestone (Japan), Goodyear (USA), Continental (Germany), Sumitomo (Japan) and Pirelli (Italy). Based on the global market sales, the top three controlled 53.5% of the world market sales (See Table 2.2)

Table 2.2 Production data of major tyre producers in 1996

Company	Outputs/units (in million units)	Output/tonnes (in million tonnes)	Market share (%)
Goodyear	178.6	2.61	16.6
Michelin	171.3	2.42	18.6
Bridgestone	169.0	2.55	18.3
Continental	76.1	1.1-1.2	not available
Sumitomo	61.5	0.8-0.9	not available
Pirelli	48.0	0.65-0.75	not available
Yokohama	21.0	0.3	not available

Source: Davis, 1997

Developments and trends in production: The primary tyre production pattern (Figure 2.2) is presented based the developments in truck tyres production at the world market. A similar situation, however, can be expected for passenger car tyre production. Compared to 1980, production of truck tyres and its predictions by year 2020, apart from countries of Eastern Europe and China, seem to be more or less stabilised or show insignificant increase.

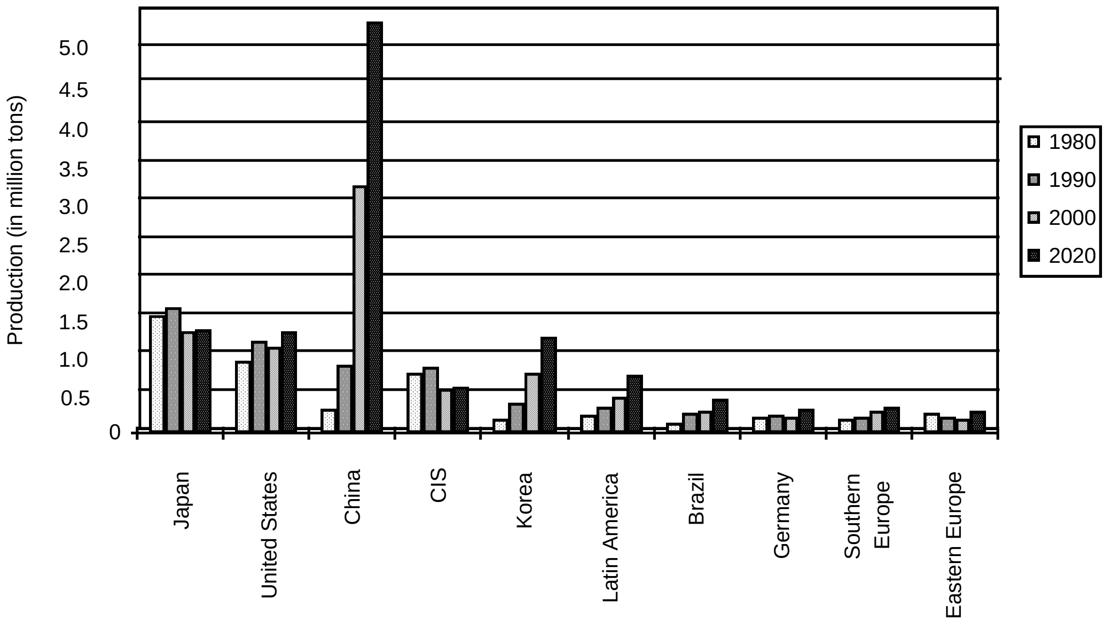

Figure 2.2 World truck tyre production in 1980-2020; Source: Smith, 1995

Stabilisation of truck tyres primary production in most industrialised countries appears to be a result of improved tyre quality which extends the life cycle of tyres. Considering that the number of motor vehicles has increased in last decades, it seems that the prolonged life cycle of a tyre to some extent has levelled out the number of tyres required to cover demands of automobile industry.

A slight decrease in truck tyre production took place between 1980-1998 in Eastern Europe. This decrease was caused mainly by transition in economies of these countries. This development in tyre production is expected to change however. By 2020, the tyre production is expected to increase.

It is expected that the most extensive increase in primary production by year 2020 will occur in the Asian newly industrialised economies. For example, China had the largest global market share about 12% of truck tyre primary production in the world already in 1990. It is expected that market share of world truck tyre production in China will increase to 32% by the end of 2000. The reason for this significant growth may come from lower prices of tyres produced in China, due to closeness from the major natural rubber suppliers, cheaper labour and energy costs.

Penetration of tyres produced in China and other Asian newly industrialised countries to Europe, which are said to be less suitable for retreading, is therefore most likely to be expected. If the tyres exported from China and other Asian newly industrialised economies are non retreadable they can represent a potential threat for efficient processing of used tyres in Europe. Therefore, it is important to verify this alleged shortcoming of these tyres.

The major trend in the tyre manufacturing with positive impact on processing of post consumed tyres is an involvement of producers in the whole life cycle of a tyre. Several top leaders such as Goodyear, Bridgestone, Firestone, Pirelli and Michelin are actively pursuing independent retreaders across Europe to help them establish continental tyre retreading networks. As a result, selling tyres is increasingly becoming a matter of cost per kilometre over the whole life time. Other manufacturers are also increasingly becoming actively involved in processing of post consumed tyres (Davis, 1997; Tyre recycling and disposal, 1996).

2.3.2 Consumption

Consumption pattern of tyres depends on two factors which include expected life span of a tyre and driver behaviour. Addressing these factors by relevant policies is a preventive measure resulting in reduction of waste. This step is essential, because prevention is considered to be the top priority in the waste management hierarchy.

Expected life span of a tyre: Improvements in the tyre manufacturing over the past 40 years have more than doubled the life span of tyres. Currently, steel belted radial passenger tyres last about 65 000 kilometres. If these tyres are properly inflated, rotated, and otherwise cared for 95 000 to 128 000 kilometres life time may be achieved. A tyre loses up to 10 % of its weight until it is disposed of. Most of the dissipated material comes from the tread which is made of rubber only. The main body of a tyre called casing, may last much longer than the tread. Usually, the entire casing is in a good state once the tread is finished.

User behaviour: Behaviour of drivers has an unmistakable influence on a tyre wear. Quick acceleration, not observing speed limits, abrupt braking and not taking into account the state of road surface are all forms of driver behaviour that cause the original tread to dwindle at a great rate. Too low tyre pressure leads to increase of rolling resistance and more heat pressure production causes increased wear of the tread. By many motorists tyre pressure checks are limited to no more than part of the garage mechanic's maintenance service. However, it appears that increasing the life span of tyres by application of more hard wearing compounds has negative consequences for the safety aspect in particular. Proper user behaviour has, additionally, a positive impact on fuel consumption and road safety.

2.3.3 Post consumption

Post consumption stage of a tyre starts when a tyre is replaced by a new one or when a vehicle is scraped. Although there is a number of options available for processing post consumed tyres, the actual post consumption stage poses some of the main concerns in the life cycle of a tyre, especially when tyres are disposed without material and energy recovery. The most commonly used processing options including their potential impacts are described further in this study.

In this report, a term *post consumed*, *waste* or *used tyre* defines a tyre at the end of its first life cycle. Considering the significant differences between the characteristics of post consumed tyres and consequently their processing options, several other terms are being used further in this report:

- *Part worn tyre* is a post consumed tyre at the end of its first life cycle. Such a tyre can be either directly reused or processed and enter its second life cycle for the purpose for which it has been originally manufactured.
- *Worn out* or *scrap tyre* is a post consumed tyre which cannot be reused for its originally intended purpose but may have a further use as a material or energy.

2.4 Conclusions on tyre characteristics

Composition of tyres predetermines the characteristics of tyres and their impact on the environment. At the end of their life cycle, tyres are of significant environmental concerns especially when they are disposed by traditional disposal methods such as landfilling. Landfill of tyres poses not only environmental and public health hazards, but it is also a waste of valuable materials and energy. After taking a closer look on production and consumption patterns, positive trends of prolonged tyre life span and tyre manufacturers involvement in the whole life cycle can be observed. This development may have positive impact on processing of post consumed tyres which will ultimately bring benefits to environment.

3. International trade of used tyres

International trade plays an important role in overall waste tyre management practices. In this respect, it is valuable to have a knowledge about the regional patterns of international trade in post consumed tyres and tyre related rubber waste. This chapter gives a statistical review of the world and European trade in used tyres and tyre related rubber waste with the aim to identify the most important international export and import patterns, and to elaborate on the main European trade flows. Furthermore, this chapter attempts to recognise driving forces for trade.

3.1 Data sources and scope

This statistical review on international trade of used tyres and tyre related rubber waste has been derived from two databases of United Nations Conference on Trade and Development (UNCTAD): Trade Analysis and Information System (TRAINS) and International Commerce Database (COMTRADE[1]). Both TRAINS and COMTRADE employ the international trade classification, the Harmonised Commodity Description and Coding System (HS).

According to the HS, used tyres and tyre related rubber waste fall into two items:
- HS 40.12.20 used pneumatic tyres and
- HS 40.04.00 waste, parings and scrap of rubber and powders and granules.

Item HS 40.12.20 covers tyres that are suitable for further use or retreading. Item HS 40.04.00 includes worn out tyres not suitable for reuse or retreading, unprocessed rubber waste as well as processed rubber waste, e.g. powders and granules. Item HS 40.04.00 has been assessed only for the European Union (EU) countries since the data does not contain information for the Eastern European countries. The databases have been compiled from statistics over the period 1990-1996.

3.2 Main trade flows in the world

In this section, the main trade flows of used tyres and tyre related rubber waste are studied and discussed. For the assessment of the world trade, the TRAINS database has been used. For the world trade review, the year 1996 have been studied. First, 1996 is the most recent year for which data is available. Second, the data for previous years has been found to be rather incomplete.

3.2.1 Used tyres

Before going into details about the trade of used tyres and tyre related rubber waste, it is interesting to compare flows of used to trade flows of new tyres. To demonstrate this, we have compared the world trade of new pneumatic tyres (motor vehicles, buses and lorries) with the trade of used pneumatic tyres. This comparison is depicted in Table 3.1. In mone-

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1 The statistical data from Belgium and Luxembourg are aggregated in the COMTRADE database

tary values, used tyres comprise almost neglectable share of only 2%. In terms of physical flows, this category accounts for approximately 14%. This contrast can be explained by the major price differences between the two commodities.

Table 3.1 World trade flows of new and used tyres in 1994

	Value (in million ECU)	Quantity (1,000 tonnes)	Average price (ECU per tonne)
New tyres	8 000	2 000	3 950
Used tyres	173	317	550
Share of new tyres	98%	86%	not available
Share of used tyres	2%	14%	not available

Source: UNCTAD, TRAINS, 1996

In 1996, the total trade in used tyres amounted to 158 million USD. The world trade pattern of import and export of used tyres is presented in Table 3.2. The TRAINS database provides figures for the top ten importing countries and top six exporting countries.

Table 3.2 Main importers and exporters of used tyres, item HS 40.12.20 in 1996

Importing country	World market (%)	Volume (1000 USD)	Exporting country	World market (%)	Volume (1000 USD)
USA	35.1	55 619.6	Japan	52.4	82 907.1
EU[2]	16.8	26 591.0	USA	7.0	11 095.4
Hong Kong	13.2	20 972.1	Germany	6.4	10 209.1
Brazil	7.0	11 095.4	Switzerland	4.5	7 122.6
Austral.	4.9	7 708.2	Korean Rep.	4.4	6 901.0
New Zealand	3.4	5 365.7	Austria	3.3	5 270.7
China	3.3	5 286.5	Others	21.9	34 774.1
Thailand	3.1	4 954.2			
Poland	2.3	3 624.6			
Canada	2.0	3 292.2			
Others	8.7	13 786.2			
Total		*158 825*	*Total*		*158 825*

Source: UNCTAD, TRAINS, 1996

The import of used tyres is concentrated mainly to the USA, the EU countries and Hong Kong. Together the importers cover more than 65% of the total world import of used tyres. The top ten importing countries cover more than 90% of the total world import of used tyres.

Japan has a dominant position on the market with 52% of the global export of used tyres. The top six world exporters including Japan, USA, Germany, Switzerland, Korean Republic and Austria cover almost 80% of the world market. The EU as a whole takes a second place in both the import and the export of the total world trade in used tyres. It should be noted that the intra-European trade can not be identified in the COMTRADE database.

[2] Note, the EU is considered as one import market, while in the export statistics, the EU countries are taken separately

3.2.2 Tyre related rubber waste

The trade in tyre related rubber waste totalled to 38 million USD in 1996. The most important flows for tyre related rubber waste in the world are listed in Table 3.3. The USA, EU, Canada and Hong Kong cover more than 75% of the total world import of tyre related rubber waste. The top ten importers cover almost 95% of the total world import. Compared to the import of used tyres, the EU has almost a double market share in tyre related rubber waste (28%). In view of export of tyre related rubber waste, the market shares are divided among a large number of countries (i.e. group “others” covers almost 50% of the total volume).

Table 3.3 Main importers and exporters of rubber waste, item HS 40.04.00 in 1996

Importing country	World market (%)	Volume (1000 USD)	Exporting country	World market (%)	Volume (1000 USD)
USA	28.64	11 405.9	USA	17.15	6 830.0
EU	28.48	11 342.2	Switzerland	11.17	4 448.4
Canada	11.56	4 603.8	Saudi Arabia	6.98	2 779.8
Hong Kong	6.53	2 600.6	Canada	6.83	2 720.0
Korea	5.71	2 274.0	Germany	4.42	1 760.3
Japan	5.46	2 174.4	France	4.09	1 628.8
Mexico	3.03	1 206.7	Others	49.36	1 9657.6
China	2.37	943.8			
Switzerland	2.14	852.2			
Norway	0.88	350.5			
Others	5.2	2 071.0			
Total		*38 825*	*Total*		*38 825*

Source: UNCTAD, TRAINS, 1996

3.2.3 Main issues in the world trade

The import and export data for used tyres and tyre related rubber waste show different patterns. In general, the global trade in used tyres and tyre related rubber waste is divided between three major players - USA, EU and Asia. The USA is a net importer of used tyres and tyre related rubber waste with a global market share of 35% and almost 30% respectively. It appears that the EU is also a net importer of used tyres and tyre related rubber waste. However, because the TRAINS database does not allow to identify the direction of trade, this statement may be misleading (Germany’s export of 6% could very well be destined to other EU countries).

3.3 Main trade flows in Europe

Review of the main trade flows within Europe, based upon the COMTRADE database, is presented separately for each trade commodity (HS 40.04.00, HS 40.12.20) while identifying the main import and export patterns.

3.3.1 Import of used tyres

Figure 3.1 gives an overview of the import pattern of used tyres in Europe. The UK is by far the largest importer of used tyres importing about 51 600 tonnes per year followed by

Germany which imports 42 700 tonnes of used tyres. Although France and the Netherlands import less than a half of the volume imported by UK, they appear to be dominant importers of used tyres in Europe importing 23 200 and 18 900 tonnes. Poland, which imports about 18 700 tonnes per year ranks as the fifth main importer of used tyres in Europe. (More detailed overview of import for the top four importers is given in the Appendix IV).

The largest bilateral flow, 33 500 tonnes per year, is between France and the UK. However, according to the export data of France, only 4% (1 412 tonnes per year) of its total export of 35 300 tonnes per year is exported to the UK. Similar inconsistencies between export and import data can be observed for Germany, France and the Netherlands which may have negative impact on the results of trade analysis.

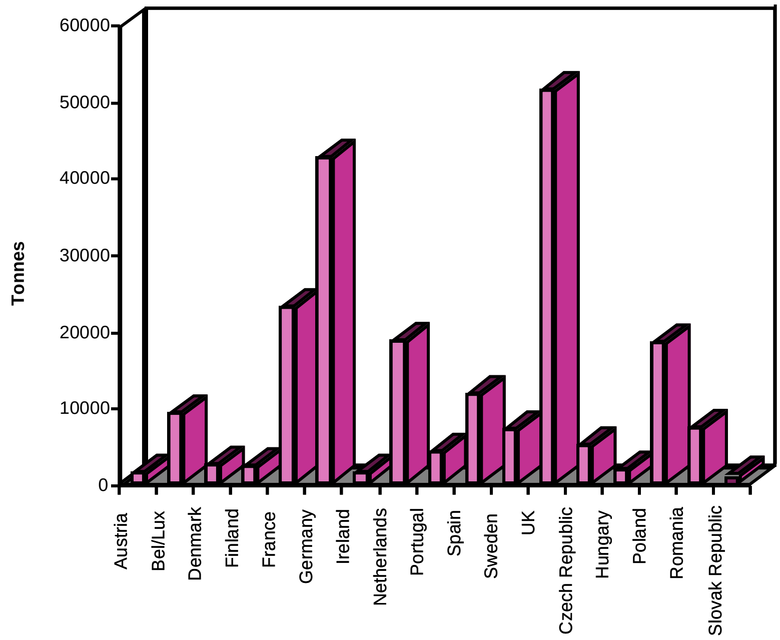


Figure 3.1 Import of used tyres (item HS 40.12.20) in 1996

Among the Central and Eastern European countries, Poland is the largest importer of used tyres with volume of 18 700 tonnes per year, followed by Romania (7 500 tonnes) and the Czech Republic (5 200 tonnes). Notably, the largest bilateral flows are between Germany and the countries of Eastern Europe. Again a great discrepancy appears to exist between export data and import data (Appendix V).

3.3.2 Export of used tyres

Export of used tyres in Europe is presented in Figure 3.2. Unfortunately, countries of Eastern Europe were excluded because the data was missing. Germany, the Netherlands and France are by far the largest exporters of used tyres in 1996. Together they cover approximately 75% of the total European export of used pneumatic tyres. Germany's export destination of 59 700 tonnes is very diverse. About 53% of the total Dutch export (51 900 tonnes) is destined to Germany and France. The main export destinations of France, almost 50% of the total export of 35 300 tonnes, are Germany and Algeria. It is interesting to note that the UK is not a major trade partner in terms of export. (Appendix VI gives an overview of the used tyres destinations of the top four exporters.)

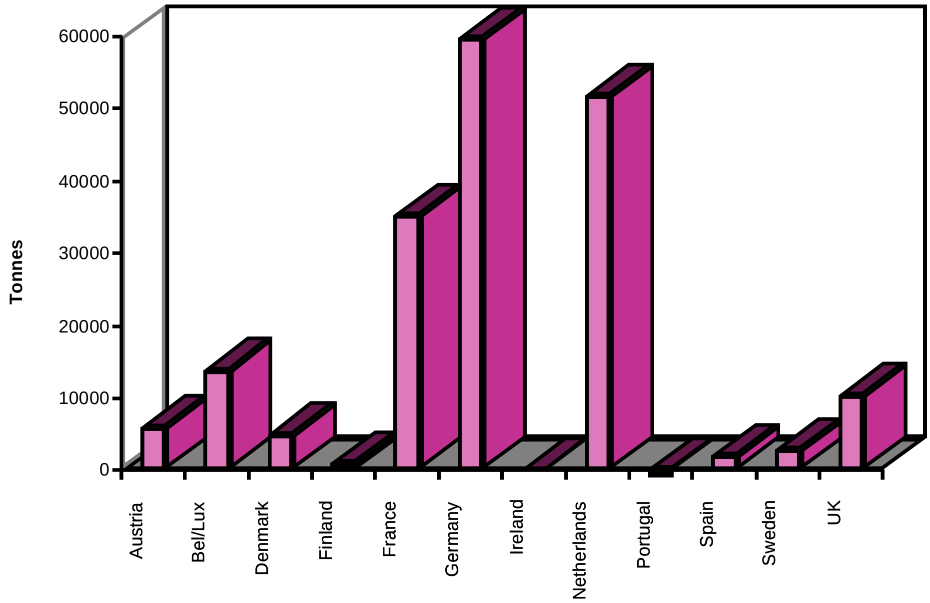


Figure 3.2 Export of used tyres (item HS 40.12.20) in 1996

3.3.3 Import of tyre related rubber waste

Figure 3.3 gives an overview of the volume of tyre related rubber waste imports in the EU in 1996. Sweden is the largest net importer of tyre related rubber waste in Europe followed by the Netherlands and Germany.

Sweden imported 50 500 tonnes of rubber waste in the studied year. Import of 39 000 tonnes is destined from Germany. Interestingly, Germany does not report any export to Sweden. Although the trade coding system is not transparent enough to specify the disposal routes of traded commodities, we assumed the imported rubber waste is destined for energy recovery. The market price of rubber waste as a rather cheap fuel is justifiable driving force for these shipments. This assumption has been confirmed by Swedish authorities, which however, questioned the traded volume. According to their statistics, the import of tyre related rubber waste to Sweden is lower by 50%.

Compared to Sweden, the Netherlands and Germany, appear to be transit countries or involved in local transboundary trade. In this respect, transportation costs appear to be limiting factors. Notably at least 40% of rubber waste imported to Germany originates in countries of Eastern Europe such as Poland and the Czech Republic (Appendix VII). Apparently, these imports include granulate traded as an inexpensive fuel around Europe.

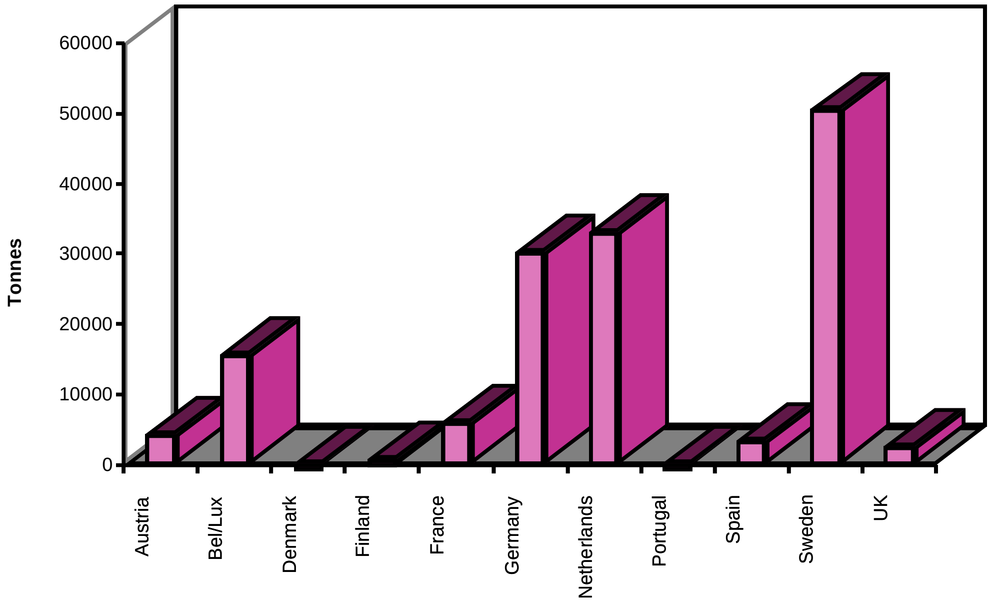


Figure 3.3 Import of tyre related rubber waste (item HS 40.04.00) in 1996

3.3.4 Export of tyre related rubber waste

Figure 3.4 gives an overview of 1996 export pattern for tyre related rubber waste in the EU. The Netherlands is the largest exporter of tyre related rubber waste with annual volume of 34 900 tonnes, followed by Germany with 18 500 and France 7 500 tonnes per year. The German export pattern of tyre related rubber waste is rather diverse destined to a large number of countries. The Dutch and French export is much more focused on a few countries directed mainly to Belgium/Luxembourg where the imported rubber waste is most likely incinerated (Appendix VIII).

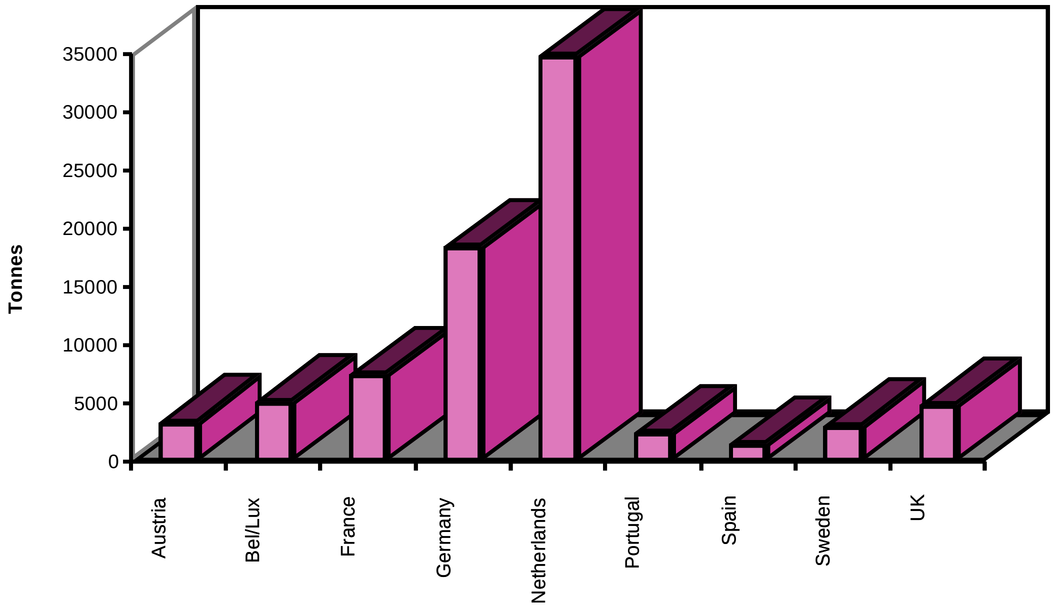


Figure 3.4 Export of rubber waste (item HS 40.12.20) in 1996

3.4 Conclusions on trade

The global trade in used tyres and tyre related rubber waste is divided between three major players - USA, EU and Asia. The USA is a net importer of used tyres and tyre related rubber waste. For the European Union and Asia, it is more difficult to extract directions of trade since it is not possible to distinguish the intra continental from the intercontinental trade in these regions.

The main actors concerning the trade of used tyres at the European level are the UK, Germany, France, the Netherlands and Poland. Figure 3.5 shows the overall situation of trade in used tyres and tyre related rubber waste in Europe for the year 1996.

The UK is an absolute net importer of used tyres. Presuming the big market for tyres in the UK, it appears that the large volume of partly worn tyres is imported for direct reuse and retreading. Germany plays an important role not only within the EU but also as a trade partner for the Central and Eastern Europe. The relatively low price of partly worn tyres and high demands for such tyres by consumers in these countries provide a large market for reuse of post consumed tyres.

The total trade volumes of tyre related rubber waste are comparable with the total trade volumes of used tyres in Europe. Sweden is by far the largest net importer of tyre related rubber waste which is mostly incinerated with energy recovery. The Netherlands is the largest exporter of rubber waste mainly directed to Belgium/ Luxembourg. However, looking at the overall trade balance, the import and export are almost identical.

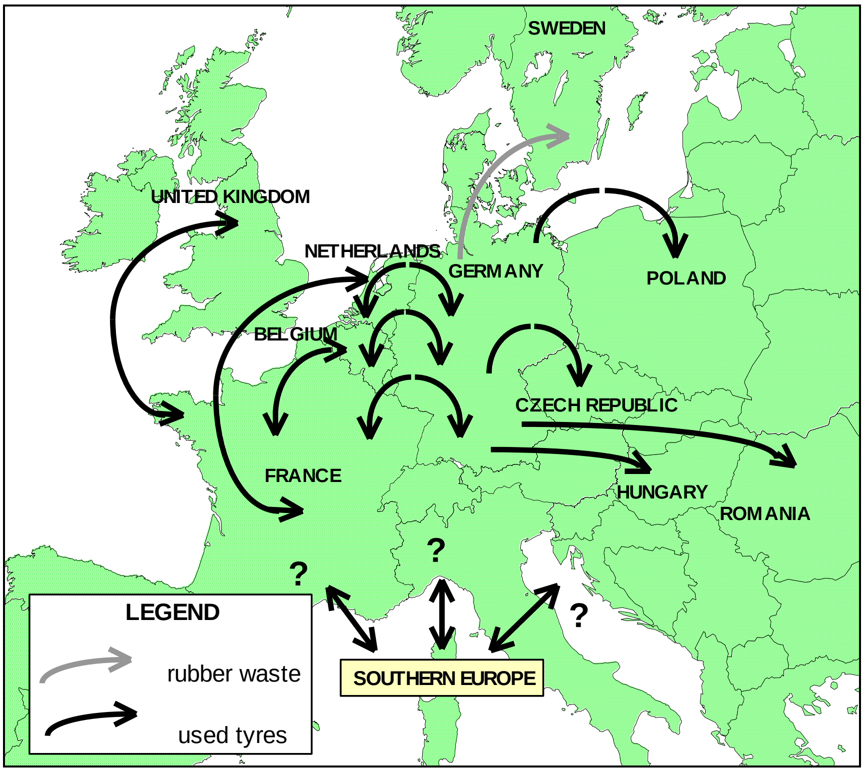


Figure 3.5 Overview of the European trade in used tyres and tyre related waste in 1996

Based on the regional trade patterns, some conclusions can be drawn with regard to driving and limiting forces of international trade. Market prices of traded commodities and transportation cost seem to be the main elements influencing the trade on used tyres and tyre related rubber waste.

Differences in *market prices* of traded used tyres and tyre related rubber justify the volumes shipped in Europe. Remarkable examples are part worn tyres imported to UK and Eastern Europe for reuse or rubber waste shipped to Sweden for energy recovery where it represents an inexpensive source of energy. In this respect, availability of processing options also plays an important role, though, it is difficult to prove this hypothesis. Since the demarcation of the products under the HS is not possible, it is difficult to identify the destined processing routes for the traded rubber commodities. The market mechanism is the absolute driving force for trade of used tyres and tyre related rubber waste in Europe.

Transportation costs which are directly linked with the distance between trading countries seems to be the limiting factor of trade in used tyres and tyre related rubber waste in Europe; these play a very important role in terms of economic feasibility. Local transboundary trade in used tyres between UK and France or trade in rubber waste between the Netherlands, Germany and Belgium are among the best examples.

The quantitative trade patterns in general are difficult to explore, because the available data is incomplete and not very accurate. There are great differences between reporting on arrivals by importing countries and reporting on the same trade flow by the exporting countries.

4. International waste tyre management policy

This chapter is intended to give an overview of the legislative and policy frameworks within which the current debate on waste management of post consumed tyres on international and EU levels is taking place. It also refers to the main stakeholders involved when dealing with issues on waste tyre management and briefly describes the role they play. Further, it provides background information on available policy instruments applicable within the waste management.

4.1 Stakeholders

Action programmes on the environment are increasingly becoming based on legislation and controls involving a large number of stakeholders. The main actors in the tyre and used tyre management business are tyre manufacturers, tyre retailers (dealers), garages, collectors, retreaders, operators of shredders, recyclers, operators of cement kilns and tyre incineration plants. In many countries, operators of landfills are actors of significance. The concept of shared responsibility applicable to environmental policy requires a much more broadly based and active involvement of all above mentioned actors including public authorities, governmental institutions and the consumers. The ultimate objective in the involvement of these stakeholders is to strike a new balance between the short term benefits of individual persons, companies and administrations and the longer term benefits of society as a whole.

4.2 Policy instruments and waste management

Until recently, most of the policies related to waste management had relied exclusively on legislative measures to pursue environmental goals. The need to bring about substantial changes in current trends and practices and to involve all sectors of the society in a full sharing of responsibility requires the use of a broader mix of policy instruments. Any effective waste management policy consists of a set of instruments available to environmental policy makers which include legislative, economic and other policy instruments.

Legislative instruments include the compulsory net legislation that prevent environmentally undesirable practices. The application of direct regulation in environmental policy has a long tradition. The legislative instruments are designed to set fundamental levels of environmental protection, to implement wider international commitments and provide necessary rules and standards. The most commonly used legislative instruments are series of regulations, permits, technical standards, bans and restrictions which provide regulatory framework for environmental policy. Additionally, setting up targets defined in a legislation is becoming an important legislative instrument.

Economic Instruments offer an alternative or complementary means for achieving waste management objectives. Various economic instruments can be put in place to internalise the external costs of various waste management options. While some view these instruments as unnecessary, interference in the market place, others advocate a total shift towards taxing those elements which are deemed undesirable. The use of economic instruments is being promoted also within the Fifth Environmental Action Programme of European Union (5EAP). Economic instruments can affect the economic costs and benefits of the alternative waste management options. They range from charges on new products, recycling or disposal fees, deposit-refund systems, grants and subsidies.

Other instruments rely on the assumption that environmental progress will be made if all the actors in society change their behaviour. Information and education campaigns, product policies, ecolabels or voluntary sectoral agreements (covenants) are all examples of other policy tools with a large potential in the waste management. Additionally, producer liability concept which provides an incentive for manufacturers to reduce the environmental impacts of their products throughout the life-cycle is being adopted for a number of waste streams. To achieve such changes, improving base line statistical data and sectoral, planning scientific research and technological development (as respect both new less-polluting technologies and technologies for solving environmental problems improved) has to be promoted.

4.3 International policy

On the international level, United Nations Program on the Environment (UNEP) and Organisation for Economic Co-operation and Development (OECD) have introduced policies relevant to the management of used tyres. Both organisations address the international movement of waste including used tyres and tyre related rubber waste.

4.3.1 Basel Convention

The used tyres have always been among the ‘hot issues’ of the *Basel Convention on the control of transboundary movements of hazardous waste and their disposal* agreed in 1989, which entered into force in May 1992. It creates a global regulatory regime to control trade in hazardous waste. In 1995, a major modification to the Convention was made. An immediate ban was proposed on the export of waste for disposal from developed to developing countries. Moreover, a ban on the export of hazardous waste for recovery was proposed in 1997.

The Technical Working Group of the Basel Convention and a number of participating parties raise the issue of used tyres as a serious problem. The underlying reason for the complaints is the lack of capacity for final disposal of tyres and the short life span related to reuse of imported tyres. In 1994, the problem of used tyres became an agenda point on the intergovernmental level.

At the 10th Meeting of the Basel Convention in April 1996, it was decided to classify *waste, parings and scrap of rubber and granules obtained therefrom* on List B, classifying it as non hazardous waste. During the same discussions some delegations requested more explicit information on *used pneumatic tyres* which deferred the decision on this subject; however, used tyres were in 1997 placed on the same list. Materials from List B are allowed to be traded without further restrictions. However, due to the lack of clarity in the classification, non hazardous materials from List B may be affected by the ban on trade (BIR, 1997).

4.3.2 OECD Decision on Control of Transfrontier Movements

The OECD Council reached a decision in 1992, which was intended to regulate and preserve the trade in secondary materials. The OECD *Decision on the Control of Transfrontier Movements of Waste Destined for Recovery Operations* states that "economically and environmentally satisfactory" waste recovery techniques should be encouraged and transboundary movement of waste is justified on these grounds. The OECD decision divides recyclable waste into three categories: green, amber and red. Tyres and tyre related rubber waste fall under the green category, according to which they are defined as non hazardous waste and may move internationally between OECD nations without any special controls.

4.4 European Union policy and legislation

The EU legislation dates back more than 20 years. Since this time, the Community have developed legislative and policy frameworks which are being implemented in order to face the waste management issues within the EU.

4.4.1 The legislative framework

The main framework directive on waste sets the background on which the European legislation and environmental policies are proposed and built up. The legislative framework which provides basis for management of used tyres consists of the following pieces of legislation supplemented by subsequent legislation addressing specific waste management problems:

- Council Directive on Waste (Council Directive 75/442/EEC);
- Council Directive amending the Directive 75/442/EEC on Waste (Council Directive 91/156/EEC);
- Council Regulation on the supervision and control of shipments of waste within, into and out of the European Community (Council Regulation 259/93/EEC).

Council Directive on Waste: The 1975 Directive on Waste sets out the main definition of waste, which at the EU level is the starting point for the definition of a used tyre. Further, it established a basis for the waste hierarchy. It calls on the Member States to promote the prevention and reduction in the production of waste, principally through the development of clean technology and marketing non polluting products. The Member States were encouraged to develop recycling or reuse of waste by any means which enables the raw materials to be extracted or energy to be recovered from the waste streams. Further under the 1975 Directive, the Member States must take appropriate steps to ensure the collection, deposit or treatment of waste without endangering human health or harming the environment.

Council Directive amending the Directive 75/442/EEC on Waste: The 1991 Directive which amended 1975 Framework Directive entered into force in April 1993. The directive provides a more clear definition of waste and obliges the Member States to give preference to the prevention and reduction of waste generation, and to the recovery of waste by reusing, recycling and by the use of waste as a source of energy. The Directive also aims at the dual objective that "the Community as a whole" shall become self sufficient in waste disposal and that Member States shall "move towards that aim individually."

Council Regulation on the supervision and control of shipments of waste within, into and out of the European Community provides a detailed framework governing movement of waste within, into and out of the European Union. The Regulation covers any shipment of waste and was intended to implement the key international agreement concerning shipment of waste, in particular the 1989 Basel Convention and 1992 OECD Decision on the control of transfrontier movement of waste destined for recovery.

The Regulation sets out the types of control that will be exerted over shipments of waste, not on the basis of its classification as hazardous or non-hazardous, but rather according to the kind of treatment it is destined for. Regulation allows Member States to close their borders to waste from the rest of the EU. Further, it bans all exports of waste for disposal out of the EU, except to those EFTA countries belonging to Basel Convention. The shipment of waste for recovery depends on particular classification of the waste, which is established using OECD green, amber and red list. Used tyres and tyre related rubber waste are placed on the green list.

4.4.2 The policy framework

Besides the legislative framework, there have been a number of other developments affecting the evolution of environmental policy implemented within the EU. The present policy framework is outlined mainly by the following documents:

- Community Strategy on Waste Management (SEC/89/934 final);
- Communication on the Review of the Community Strategy for Waste Management (COM/96/399 final);
- Priority Waste Stream Programme (Resolution of the Council concerning waste management, 90/C 122/02);
- Fifth Action Programme for the Environment and the Progress Report (93/C138/01, COM/95/624 final).

Community Strategy on Waste Management: In 1989, the Commission adopted a report on the Community's Waste Management Strategy. The aim of the strategy was to set out clear principles and strategies to be translated into action in the period up to 2000. The report also defined the waste hierarchy in which emphasis was laid on waste prevention, followed by promotion of reuse and recycling, and optimisation of final disposal methods for waste which is not reused.

Communication on the Review of the Community Strategy for Waste Management: In 1996, the European Commission reviewed the Strategy for Waste Management while it formally introduces the principle of producer responsibility and confirms the hierarchy of waste management principles established by the 1989 waste strategy. The implementation of this hierarchy should be guided by considering the best environmental solution taking into account economic and social costs.

The concept of *waste hierarchy* is based on common sense considerations and it underlies the European waste policy. The concept proposes the following list of waste management options in descending order of priority: first comes the prevention of waste generation, then recovery and last final disposal (Table 4.1).

Table 4.1 The waste hierarchy principles of the EU waste management strategy

Objectives	Specific measures

Prevention	Application of cradle to grave approaches
	Promotion of clean technologies and products
	Establishment of technical standards
	Information and education
Recovery	Product reuse
	Material recovery (material recycling)
	Energy recovery (incineration with energy recovery, incineration in cement kilns and other industrial operations)
Final disposal	Incineration without energy recovery
	Landfill of waste

Source: COM/96/399 final, 1996

The key objective of the Community waste policy is *prevention* which can be achieved by application of such methods as the life cycle analysis and other cradle to grave approaches when designing products, promotion of clean technologies, establishing of technical standards for products and by education of consumers which can contribute to progressive changes in the consumption patterns.

The *recovery* concept has to be considered in its triple dimension: *reuse*, *material recovery* (recycling) and *energy recovery*. As regards terminology, the notion of recycling should be limited to material recovery. Waste which cannot be avoided should be recovered according to one of these methods.

Reuse of product should be further encouraged since it helps to avoid waste generation. Post consumed products which cannot be reused can be otherwise recovered by means of *material recovery*, which means that materials contained in the waste are reprocessed in order to make new products or by *energy recovery* operations, where the energy is extracted by the use of the waste as a fuel. "Preference should be given, where environmentally sound, to the recovery of material over energy recovery operations." The Communication tempers this assessment, with an important qualification: "It will nevertheless be necessary to take into account the environmental, economic and scientific effects of either option. The evaluation of these effects could lead, in certain cases, to preference being given to the energy recovery option."

The Communication notes that waste recovery operations are an increasingly important sources of energy and indicates that it may be necessary for the Commission to set EU quality requirement defining whether only waste above a certain calorific value should be considered as waste for energy recovery. The same strict standards, in principle, should apply for waste whether it is treated in industrial installations or in waste treatment installations; "particular attention will have to be paid to installations which originally had not been designed to use waste as fuel substitute—as in the case with cement kilns." (COM/96/399final).

Final disposal should be safe and limited to waste for which no possibility of recovery exists. It is carried out mainly by waste incineration without energy recovery and landfill of waste. Although incineration of waste reduces the volume of waste it does not contribute to saving resources. Consequently, energy recovery should be promoted for all incineration operations. The landfilling of waste should be seen, in principle, as the last and least best solution (COM/96/399final).

The Priority Waste Stream Programme: Following the *Council Resolution Concerning Waste Management* of 7 May 1990 (90/C 122/02), which asked for EC wide actions for particular types of waste, a priority waste stream programme was set up by the Commission in 1991. The aim of the program was to identify waste streams which are particularly harmful to the environment with a view to imposing specific regulatory requirements on them. The Programme followed the strategy set out in the EU 1989 Waste Management Strategy, calling for a hierarchy of waste treatment and disposal options to be established.

About thirty waste streams were identified and priorities were given to some of them including used tyres. A working group which consisted of representatives from national governments, the Commission services, suppliers of raw materials, manufacturers, product retailers, environmental and consumer protection associations was appointed and charged with preparing a working document which would serve as a proposal for recommendations concerning the prevention, recovery and disposal of used tyres.

The group has prepared a *Proposal from the Working Group to the European Commission for Recommendation of the Prevention, Recovery and Disposal of Used Pneumatic Tyres (COM/XI/454/93-EN)* in which the group made its recommendations within the framework following the hierarchy. The target set by the project group was to abandon, before the year 2000, the traditional disposal techniques (incineration without energy recovery and landfill) by following principles of the waste hierarchy (*Table 4.1*).

Table 4.1 Recommended hierarchy of waste management option for used tyres

Subject	Objective	Level
Prevention	Prevent waste to be formed	An increase of the average life span of a tyre by 5%
Retreading	Reuse the tyres by renewing the tyre surface	An increase of the share of retreaded tyres to 25%
Recovery	Reuse the tyre material • by using whole tyres for other uses • by using materials from used tyres • by burning used tyres (as substitute fuel or incineration with energy recovery)	An increase of the share of recovered tyres to 65%
Collection	Take care that every tyre is returned	A “close 100%” collection rate
Disposal	Waste phase	To abandon the final disposal by means of landfilling or incineration without energy recovery

Source: COM/XI/454/93-EN, 1993

The recommendation of the working group was that there should not be European legislation to cover used tyres, but there should be recommendation by the Commission which would be implemented by voluntary agreements in each of the Member States, therefore, leaving it to industry and the Member States to sort out and find a solution. The Working Group, however, recommended an amendment to the Landfill Directive to institute a ban on landfill of used tyres. This proposal have been subsumed in a revised Proposal for a Council Directive on the Landfill of Waste (COM/97/105 final). Although neither of these recommendations have been fully implemented yet, it does reflect the direction in which policy is moving.

Although the Priority Waste Stream Program has not reach obligatory legislative statutes, its recommendations promoted discussions. Consequently, several Member states incorporated them into their national policies.

Fifth Action Programme for the Environment (5EAP) and the Progress Report: The 5EAP, "Towards Sustainability" endorsed in February 1993 is the EU's blueprint for action in the field of the environment until 2000. It reflected a fundamental shift in priorities compared to the previous programmes, which had focused on the need for environmental protection legislation. The goals at the heart of the 5EAP are:

- Sustainable development through partnership and shared responsibility;
- Integration of environmental considerations into other policy areas;
- Broadening the range of policy instruments to supplement Directives and Regulations;
- Implementation and enforcement of EU legislation.

The Programme recognises the need for an active role of all economic actors involved in the pursuit of "sustainable development". This objective can be achieved on the basis of the principle of shared responsibility. This principle has to be extended to the used tyres, with action and costs being shared between various actors, such as tyre producers and dealers, car manufacturers, transport companies. It also recommends that the economic instruments, proposed in the 5EAP, should be accompanied by an effective legislative framework.

The 5EAP recognises that "management of waste generated within the Community will be a key task of the 1990s." *Waste management priorities under the 5EAP* seeks to build on the framework legislation published by the Community and its 1989 Strategy on Waste Management. It reconfirms that the waste hierarchy defined by the strategy "will be pursued and reinforced under this Programme."

The 5EAP Progress Report includes progress made in relation to waste management at the EU and Member State level. Based on the Report, the following trends can be recognised:

- Development of sustainable waste management strategies;
- Increase of tax and fees on landfill in most of the Member States;
- Introduction of ban on landfill of combustible waste in selected Member States;
- Producer responsibility introduced in several Member States.

4.4.3 New developments in EU policy

Within the existing environmental policy frameworks new trends relevant to waste management on used tyres evolve. At the international level, the following can be recognised:

- Proposal for Directive on the Landfill of Waste (COM/97/105 final);
- Proposal for Directive on environmentally friendly handling of End of Life Vehicles (COM/97/358 final);
- Expected Proposal for Directive on Incineration of Waste;

Proposal for Directive on the Landfill of Waste: The Commission submitted a proposal for the Directive on 22 July, 1991 (subsequently revised in 1993). In 1995, a common position on the amended proposal was reached by the Council of Ministers. The European Parliament, however, did not find the level of environmental protection sufficient and therefore in May 1996, rejected it. Subsequently, in June 1996, the Council invited the Commission to present a new Proposal on the Landfill of Waste. Issue of the proposal, is expected by the end of 1998.

The proposed Directive harmonising the rules on landfill of waste in the EU takes into account *ban on landfill of used tyres* proposed by the Priority Waste Stream Group in its final conclusions. According to the Directive, "Member States shall ensure" that "whole used tyres from two years from the date of entry into force of this Directive and shredded used tyres five years from this date (excluding in both instances bicycle tyres and tyres with an outside diameter above 1400 mm)" are not accepted in a landfill (COM/97/105 Art.5, 2d).

If implemented, the ban on landfill will have positive environmental consequences on management of used tyres and tyre related waste. However, some EU countries, especially cohesion countries might face difficulties with the implementation of the Directive. In this respect, this might constrain monitoring of conversion of the Directive in the single countries.

Proposal for Directive on End of Life Vehicles: In July 1997, the European Commission adopted a Proposal for a Directive which makes vehicle dismantling and recycling more environmentally friendly, sets clear quantified targets for reuse, recycling and recovery of vehicles and their components and pushes producers to manufacture new vehicles also with a view to their recyclability (Table 4.3). The first reading of the Proposal is scheduled for October 1998.

Table 4.2 Proposed targets for end of life vehicles

Option	Target for 2005 (weight per vehicle)	Target for 2015 (weight per vehicle)
Reuse/recovery	85%	95%
Reuse/recycling	80%	85%

Source: COM/97/358 final, 1997

The proposal respects the hierarchy of priorities established by the reviewed EU waste management strategy, by giving to material recycling a clear priority over energy recovery. It also applies the important principle of producers responsibility by establishing that collection and recycling of end of life vehicles shall not be a burden of public authorities but shall be the responsibility of the automotive sector's economic operators.

4.5 Conclusions on international policy

The developments in policies on international and EU levels have direct impacts on the national waste management strategies and frameworks in Europe including both Member States and accession countries. Therefore, it is important to highlight the main features and trends evolving on the supranational level.

In accordance with the international and EU regulations, *shipment of waste tyres* is governed as trade in non hazardous waste while tyres are listed on the *green list* (OECD, EU Regulation on shipments of waste) and *B list* (Basel Convention). Waste on the green and B list is commonly traded without further restrictions unless otherwise specified.

Waste hierarchy, which underlies the European waste policy, is an important concept applied in the EU waste management strategy. It proposes a list of waste management options which are defined in descending order of priorities including the prevention, recovery and final disposal. The principles of hierarchy apply to all waste streams, including used tyres.

Based on the recommendations prepared by the Priority Waste Stream Group, several features in tyre management have been discussed in EU, whereas the degree of implementation on the EU level is still limited. *Ban on landfill* of used tyres and tyre waste, included in Proposal for Directive on the Landfill of Waste is among the most important recommendations which are expected to be implemented. If implemented the ban on landfill will promote environmentally more sound waste management practices which will have positive impacts on the environment.

Stetting *targets* for used tyres and tyre waste, specified for all individual management routes including prevention and collection, is another trend which evolved on the EU level. Although the implementation of targets set for tyres on the EU level is rather uncertain, these play important role in setting national targets all around Europe.

In addition, *voluntary agreements* has been recognised within the EU as a primary measure which should be considered within national policies when managing the waste tyre streams. Voluntary approach in combination with the *producer responsibility* is recommended also by the reviewed 1996 Community Strategy for Waste Management which calls for their adoption in national waste management strategies.

5. Waste tyre management options

At the end of their first life cycle, tyres become waste with significant streams. The physical characteristics of a tyre as well as its chemical constituents make waste management of post consumed tyres a difficult task. In accordance with the generally accepted recovery and disposal alternatives within the waste hierarchy, various options are available for safe and efficient post consumed tyre management.

This chapter discusses the most common used tyre management practices and highlights their environmental and economic aspects, current markets and their potentials in Europe. Priority is given to the most widely used options and available technologies with foreseeable future. In accordance with the waste hierarchy, Figure 5.1 shows classification of processing options as they are considered in this study.

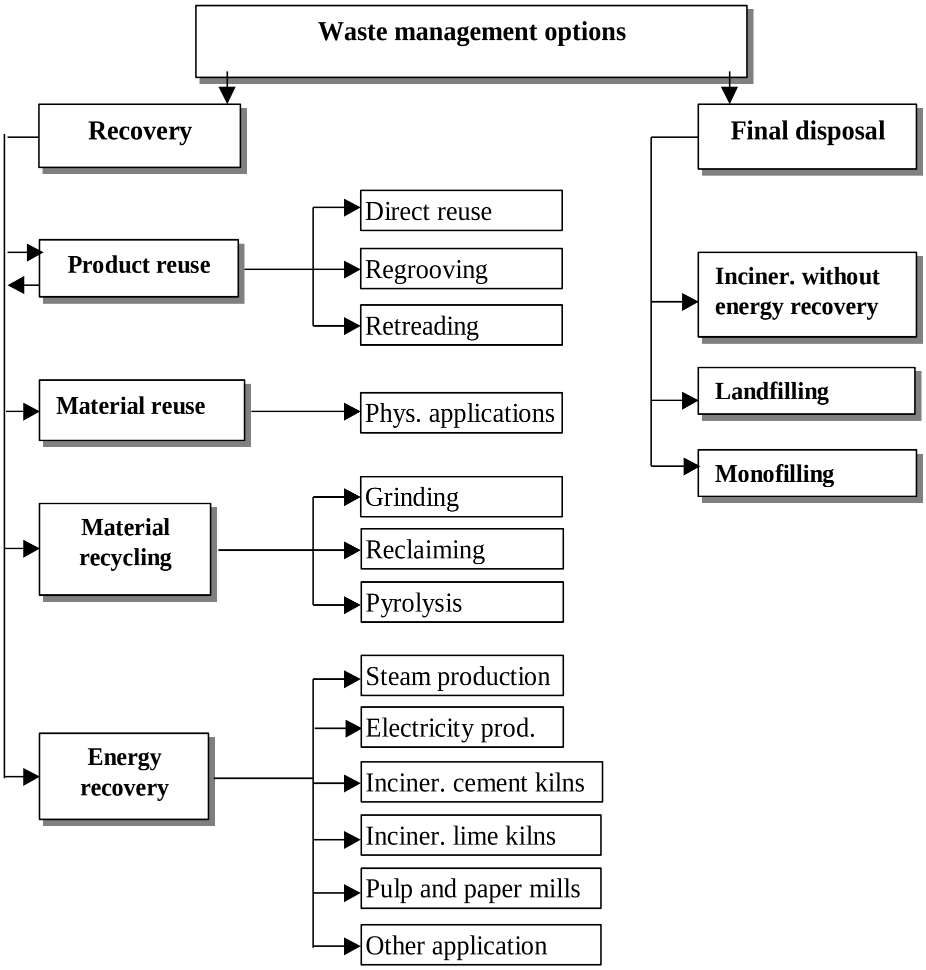


Figure 5.1 Management options of post consumed tyres

5.1 Product reuse

Product reuse ranks on the top of recovery options in the waste hierarchy. It includes the options which aim at utilisation of partly worn tyres for the purpose for which they have been originally manufactured. Product reuse brings environmental benefits in terms of reduced waste volume and saved energy necessary for production of new tyres. From economic point of view, it leads to significant cost reduction for tyre consumers. Product reuse includes: *direct reuse*, *regrooving* and *retreading.*

5.1.1 Direct reuse

The simplest way of product reuse is direct reuse. It depends on the tread depth standard, which is 1.6 mm for Europe. In many countries, the official standards are often overridden by customers preferences. Frequently, drivers replace tyres before this minimum tread depth is reached, whereas, the replaced tyres enter international trade for their direct reuse.

The environmental impacts of tyres traded for their direct reuse on international and national levels differ. From international point of view, direct reuse prolongs life span of a tyre which brings global environmental benefits. However, import of tyres for direct reuse generates additional rubber waste on the national level. This trend has often negative environmental consequences, especially for countries with lower environmental standards where incineration without energy recovery and landfilling are still common waste management practices.

Currently, Germany and the Netherlands are recognised to discard tyres before they reach the minimum tread depth, ultimately the UK and Eastern Europe are well known for providing a market for those tyres (The World Tyre Industry, 1997).

5.1.2 Regrooving

Regrooving is the cheapest method of renewing a part worn tyre. In this method, a new pattern is grooved into the tread base which remains after the pattern has been worn away by use. This technique is carried out primarily on truck tyres since these are designed with enough tread thickness.

The effectiveness of regrooving is still a conflicting issue. Some tyre manufacturers, such as Michelin, state that their tyres are specifically designed to be regrooved. If the process is carried out correctly, about 30% extra mileage will be obtained for only 2.5% of the cost of a new tyre (The World Tyre Industry, 1997). On the contrary, retreaders oppose regrooving. They consider regrooving as an obstacle to the supply of good quality casings to their business. If performed in inappropriate way, regrooving can make further retreading more difficult, more expensive and in some cases even unfeasible.

5.1.3 Retreading

Part worn tyres, which tread depth has reached the minimum legal limit, can be retreaded and then used for the original purpose. The process starts with examination of the casing and buffing which removes remaining original tread. A new fresh patterned tread is applied to the casing and cured for a proper time, temperature and pressure. Two technologies are used: hot retreading (the mould cure process) and cold retreading (the pre-cure process). Hot retreading takes place in a mould which creates a new tread design; heat and pressure are used for vulcanisation. In cold retreading, the tread is moulded and cured in advance and then chemically bound to the prepared casing; the vulcanisation process is completed in a simple curing chamber.

The environmental impacts of the actual retreading process are not of major concern. Air emissions in terms of hydrocarbons are released at the cementing stage since organic solvents are applied. Particulates can be emitted during buffing. However, these emissions can be decreased by appropriate abatement measures. Other outputs are rejected tyres and rubber scrap, represents approximately 10% of the tyre weight, generated by buffing. These materials are recycled or incinerated with energy recovery often within the retreading.

Retreading brings significant environmental and economic benefits, because it extends the tyre life span. It saves 80% of raw material and energy necessary for production of a new tyre and reduces the quantity of waste to be disposed. Although the price of retreaded tyres is between 30-50% lower than the price of a new tyre, they deliver nearly the same mileage as new tyres (Ferrer, 1996; ETRA, 1996).

Today, retreading is more common for truck compraed to passenger car tyres. About 80% of truck tyres is suitable for retreading. In case of passenger car tyres, approximately 20% can be retreaded (Information document on used tyres, 1991). In average, car tyres are usually retreaded only once, bus tyres 3 times and aircraft tyres 8 times. Truck tyres can be retreaded in average 3 to 4 times; however, generally they are retreaded less times (average 1.5 times in the Netherlands, 2.5 times in Eastern Europe).

Despite of the well-known economic and environmental advantages, retreading in most European countries commands low percentage in replacement of passenger car and truck tyres (Tyre Recycling and Disposal, 1997; RAPRA, 1996). Difficulty in supply of retreadable casings, competition with cheap non retreadable tyres and poor reputation of retreads' quality are some of the barriers to wider use of retreads.

Co-operation between producers of new tyres and retreaders can improve the supply of retreadable casings. It is important that the design and construction of new tyres takes into consideration retreading. Introduction of quality standards for retredability of new tyres could stimulate tyre producers in improving their products. It will also reduce competition between retreadable tyres and non retreadable tyres. In order to avoid the general perception that retreads are of low quality, requirement of internationally recognised quality criteria (ISO 9 000) could contribute to improving the image of retreaded tyres.

Considering its economic and environmental benefits, retreading should be seen as the first step in tyre post consumption stage. If a tyre does not meet the technical requirements for further retreading, the tyre life cycle may be closed with material reuse, material recycling or energy recovery alternatives.

5.2 Material reuse

When a tyre can not be used for its original purpose any more, it can enter a new life as another structural object. There is a large potential for the utilisation of whole, cut, sliced or stamped tyres in various physical applications.

The most common *physical applications* of used tyres are:
- Civil engineering works to take advantages of sound and impact absorption properties such as highway crash barriers, sound absorbing walls, boat fenders on harbour walls;
- Coastal protection and artificial reefs;
- Insulation in building foundations and road base material;
- Consolidation of steep slopes on roadway sides;
- Cover material in agriculture applications and construction material for landfills;
- Material to be cut up into shoe soles or other simple rubber goods like mats, floor tiles, dock fenders, muffler hungers, support pads for back hoes, well chocks, brake pads, light weight and flexible tanks, clothing accessories such as belts, handbags and buttons.

The largest potential areas of useful physical application for scrap tyres are in the civil engineering field as construction material for landfills and coastal protection. High permeability, good thermal characteristics, stability and lower price than other aggregates are the most important features which make a tyre useful in these applications.

Considering the stability and potential environmental risk of tyres, it is essential to ensure that the use of tyres for material reuse does not have negative environmental impact. The studies so far, do not prove any toxicity or leaching when tyres are used in physical applications. However, further research on environmental and risk assessment for individual physical applications of used tyres is highly required.

In Europe, physical applications amount to less than 10% of the total volume of tyre production. In some countries such as Denmark, France and Spain these applications are more common than in others. However, the reuse of used tyres in their original form is very limited.

5.3 Material recovery

Once tyres can no longer be utilised via product or material reuse, they can be used as a source of material to produce new articles, often called material recovery or recycling. In this report, the term material recovery is used. The options of material recovery included are *grinding*, *reclaiming* and *pyrolysis*.

5.3.1 Grinding

Used tyres and tyre related rubber waste can be used to produce rubber crumb or granulate. Depending on the technology and temperature applied during the process, there are two main methods of grinding: *mechanical grinding* and *cryogenic grinding*.

In *mechanical grinding*, scrap tyres and tyre related rubber waste are reduced into various particle sizes. After grinding the material, steel and textile are removed. In the *cryogenic grinding* process the whole tyres are cooled down to the below the glass transition temperature, using liquid nitrogen. The cooled rubber is reduced to a very fine powder. The process enables rapid separation of textile, steel and rubber.

In view of its environmental performance, grinding is an energy intensive process and has relatively high dust emissions. The consumption of liquid nitrogen in cryogenic grinding is relatively high, about 0.5-1 kg per 1 kg of input. The use of coolant leads to increase in cost; therefore, its price is the main factor which influences the feasibility of this process. The economic and environmental advantage of grinding is that it generates recyclable rubber and useful by products such as steel and textile, which also can be recycled.

There is a variety of applications for rubber granulate. The most common application of granulate is in rubberised asphalt. Although this seems to be a promising outlet for recycled rubber, because of its relatively high cost this application is not widespread in Europe. Additionally, its long term environmental performance is uncertain. Other applications include: sport surfaces, roofing material, carpet underlay, thermoplastic and rubber blends, noise barriers and many others.

The number of applications for granulate provides substantial potential for rubber recycling. However, the demand from the market is insufficient to justify the recovery of tyre materials. Since problems of an economic nature exist, related to competition from other products available on the market, public sector intervention is desirable to encourage the use of recycled material. Additionally, research for new applications of granulate may stimulate development of new markets for recycled rubber.

Belgium, Denmark, Germany, Italy and Sweden recycle up to 15% of the total volume of generated used tyres. The numbers include all material recycling routes. Considering the potential market for end products using recycled rubber the material recovery options are expected to increase in Europe.

5.3.2 Reclaiming

In general, the rubber reclaim is produced by chemical processing of size reduced tyres, oil, water and additives. The resulting compound is submitted to a further thermo-mechanical or high pressure steam process where additives are incorporated depending on the final product requirements. The final product is reclaim.

The individual reclaiming methods have different environmental impacts depending on the technology and chemical agents applied during the process. The direct process emissions are of minor importance compared to emissions associated with high energy consumption. However, the process brings savings of raw rubber and other compounding ingredients by virtue of reclaim usage in rubber compounds.

Reclaim can be used in high value commercial applications requiring high performing rubber such as tyres, bicycle tyres, automotive moulded parts, carpet underlayers, battery boxes, solid tyres, conveyor belts, packaging materials, soles and heels, etc. Compared to virgin rubber compounds reclaim is almost half the price. Using rubber reclaim can be even more profitable for the tyre industry, especially when production waste is recycled and reused within the factory where it is generated. This might result in additional revenues from eliminating disposal fees and transportation cost (Dierkes, 1996).

In the last years, the reclaim industry has declined. The main causes have been substitution of raw rubber by other materials, decrease in prices of raw materials, high cost of reclaimed rubber and sharp raising of the quality requirements for rubber articles. Unfortunately, due to technological problems, the combining of reclaimed rubber with other compounds at an economic cost still remains questionable. However, the market potential for reclaim is substantial and in this respect investigation for new applications is necessary.

5.3.3 Pyrolysis

Pyrolysis is a resource recovery process which can recover from used tyres useful secondary raw materials. The process consists of chemical decomposition of organic compounds by heating in total or partial absence of oxygen. The main products of the pyrolytic treatment of used tyres are carbon black, aromatic oil, gas and scrap steel. The quality and amount of individual products depend on the technology and the pyrolytic conditions. About 20% of the tyre volume is necessary as an initial energy input to start the process while the generated gas can be used to run the operation.

Pyrolysis has not yet shown to be economically feasible due to high capital costs, uncertainties in a continuous availability of tyres and lack of market for the end products. The products obtained from pyrolysis such as carbon black, oil and gas have properties that in general would allow their easy use as raw materials. However, because of low quality and high contamination of these products it has proved to be very difficult to develop a market for them. Many commercial scale pyrolytic plants have tended to fail because of the low value of the end products in relation to the capital and operational costs. Generally, these are used for energy generation which is neither economically efficient nor environmentally sound.

Depending on the technology, the direct process emissions include relatively high emissions of SO_2 reaching up to 285 mg/m^3 thus exceeding widely accepted national limits (200 mg/m^3) and other common pollutants such as CO_2, CO, NO_x, and dust. However, these can be avoided by appropriate pollution abatement technology (Kasteren, 1998).

Although some studies have been conducted at research institutes and universities, there are no pyrolytic plants operating on a commercial scale in Europe. Currently, a commercial pyrolytic unit is being constructed by Titan Technology (USA) in Austria (Forman, 1998; Phare, 1997). If this plant will run successfully, similar plants are planned in Belgium and Portugal. Additionally, a private company is preparing a feasibility study for construction of large scale pyrolytic plant in the Netherlands. Nevertheless, the key to whether pyrolysis can be more than just a scientific promise will remain the availability of tyres, quality and potential markets for its end products.

5.4 Energy recovery

The chemical composition of a tyre, particularly its large hydrocarbon content, and the need for supplementary fuels provide an inducement for incineration of tyres in energy intensive operations and industries. Even though according to the waste hierarchy principles material recovery is preferred to energy recovery, processing tyres with energy recovery seems to be a socially viable management option at least in the short and medium term until material recycling becomes a more feasible alternative. Several applications of post consumed tyres for energy recovery with the most significant potential markets are production of steam, production of electricity, incineration in cement kilns, lime kilns, paper mill boilers and application in other industries.

5.4.1 Production of steam

Combustion of tyres for steam recovery has its market in the tyre production and retreading industries. Scrap tyres and rubber waste are burned in the retreading plants and produced steam is used mainly for the vulcanisation process. At the present, there is a limited number of retreading companies in Europe burning used tyres for steam production. From economic and environmental point of view, benefits of steam recovery in tyre and retreading industries are derived from reduced disposal and transportation, consequently, reduced costs and emissions.

5.4.2 Production of electricity

In order to minimise fuel costs *waste tyres incineration plants* add whole or shredded tyres, known under the term tyre derived fuel (TDF), to supplement other conventional fuels. The process comprises of combustion, steam production and flue gas treatment. The steam, which is produced in boilers, is converted into electricity.

Concerns about emissions from incinerators are increasing as environmental pollution standards in Europe are becoming more strict. Even though the volume of emissions from tyre burning plants generates some uncertainties about various incineration routes, efficient technologic solutions are available and their use should be promoted rather than denying this recovery route.

Dedicated tyres to energy power plants are rather recent power plants designed to burn up tyres as a principal fuel. Although, their popularity is expected to increase in areas with large volumes of waste tyre generation, only a small number of such plants are in operation at present in Europe. Several smaller plants are operating in Germany, France and Italy. The largest plant in Europe is Elm Energy Wolverhampton, England, with an electricity output of 175 000 MWh and consumption 94 000 tonnes of worn out tyres per year which is about 15 % of country's total used tyre generation (Elm Wolverhamptom, 1994; BLIC, 1998).

5.4.3 Incineration in cement kilns

Incineration of tyres as a supplemental fuel in cement kilns is an attractive method of processing worn out tyres. Depending on the technology used, cement kilns can burn whole tyres up to 20-25% of their fuel intake or TDF (shredded tyres) up to 5% of the total fuel consumption. Within this inputs, the process emissions appear to be not affecting the total emission outputs.

Burning of whole tyres is preferred to use of TDF by companies because it can bring additional revenues from collected disposal fee which is usually lower than recycling fee. Frequently, the rubber tread from used tyres entering the cement kiln and steel belt containing recyclable steel are removed and recycled which adds to both economic and environmental performance of tyres designated for incineration in cement kilns. In some countries, TDF is considered to be an alternative fuel which has to be purchased. However, the number of such examples is rather limited. More common situation is receiving this fuel without any compensation (ARN, 1998; Ševčík, 1998, ENCI, 1998).

A major advantage of using worn out tyres in cement kilns is that it does not generate solid waste because the ash residues from the tyre combustion are bound in the final product. Further, the steel wire of the tyres provides iron which enhances performance of the end product. Sulphur emissions are not of a major concern as the sulphur is transformed and bound in gypsum which is added to the final product. The combustion of tyres takes place at lower temperatures which reduces nitrous oxides compared to other fuels (Jones et al, 1995; Autoexpert, 1998).

In Europe, USA, Japan and Korea, cement kilns are one of the most common end users of energy content of tyres. In some countries, such as Austria, France, Germany and Sweden incineration in cement kilns comprises up to 65% of the total used tyre generation and thus forms an important used tyre management alternative.

However, there are several principal impediments to wider use of tyres in cement kilns. These include reliability on scrap tyres supply, use of competing fuels such as hazardous waste and solvents or resistance against burning tyres in the cement kilns often associated with general opposition against cement industry and its environmental performance.

5.4.4 Incineration in lime kilns

The high calorific value of tyres and TDF is clearly of interest to lime producing factories. Although, the lime production process is very similar to cement production, the use of scrap tyres and TDF in lime kilns is limited because under certain circumstances it can have impact on the quality of final product. However, burning scrap tyres in lime kilns is a rather new market which has an unexploited potential in Europe.

5.4.5 Incineration in pulp and paper mill boilers

Pulp and paper mills have incineration units to produce energy required for the production process in which post consumed tyres can be used as a supplemental fuel. The optimal TDF comprises of dewired shredded tyres. Dewiring reduces metal concentration in boiler. Even though this processing option of used tyres is not among the most widespread in Europe, in the USA it foresees similar quantities being used as for the cement industry. The volume of emissions depends on operating conditions, pollution control equipment and volume of TDF incinerated (Barlaz et al, 1993; Serumgrad, 1997).

5.4.6 Other industrial applications

There are several other types of industrial applications which have a potential for using waste tyres for energy recovery. Such facilities include: utility boilers, industrial boilers, iron cupola foundries, copper smelters and many others . At present, use of tyres in the above mentioned facilities is very limited, often in the early stage of introduction.

5.5 Final disposal

Despite of the preference for product reuse, material recycling and energy recovery in the waste hierarchy, final disposal without material and energy recovery is still a common practice. Frequently, low prices of landfill which do not reflect the real cost of the economic and environmental damage, offer no incentives to other waste management options.

Disposal of tyres without recovery, in the broader economic and environmental context, is waste of materials and energy. It has negative environmental impacts which can be avoided when other waste management practices ranking far before the final disposal in the waste hierarchy are applied. Final disposal includes incineration without energy recovery, disposal in landfill and disposal in monofill.

5.5.1 Incineration without energy recovery

Incineration of scrap tyres without energy recovery is one of the least desired disposal options. The only advantage of incineration is that it reduces the volume of waste and thus saves landfill space. The disadvantage is that it contributes to additional air emissions and loss of valuable energy. It is no economically nor environmentally sound disposal route. On the European scale, application of this option is limited to illegal small scale burning, often in open air. Because of undesirable environmental impacts of incineration without energy recovery, strict regulations should be applied while incineration with energy recovery should be promoted.

5.5.2 Landfilling

Landfill of waste tyres has negative impacts on the environment. When disposed of in landfills, scrap tyres occupy large space and remain intact for decades posing increased environmental and public health risks related to possible leakage and danger of ignition with uncontrolled burning. Furthermore, when whole tyres are buried in a landfill they trap air and have tendency to migrate to the top of a closed landfill breaking the sanitary landfill cap and causing costly damages to the landfill cover which increases the instability of sites. The thoroid shape of tyres combined with rainwater, windblown pollen and dust trapped within tyres creates favourable environmental for pests and rodents which ultimately increases health hazards.

Even though disposal of waste tyres in landfills has been prohibited in several European countries and ban on landfill is under discussion on EU level, a large volume of used tyres is still disposed of by landfill in Europe. In 1995, about 46 per cent of the total post consumed tyres were landfilled in EU (EEA, 1995).

5.5.3 Monofilling

A scrap tyre monofill is a variation of a landfill. Compared to landfills, monofills are more desirable because they contain only scrap tyres which can be utilised for recovery of materials and energy in the future. Because of more strict management practices in monofills their environmental risks are lower compared to landfills.

After introducing ban on landfill, monofills can be reconsidered as temporary short term solutions in those European countries where capacities for processing used tyres are limited and problems with implementation of the ban are expected. The potential advantage of such monofills is that they can be reconsidered as future used tyre collection sites and distribution centres. However, examples from Canada and USA show that monofill sites become frequently abandoned without processing these tyres in stock.

5.6 Conclusions on management options

There are several waste management alternatives which address the challenge of post consumed tyres. Although the preference should be given to reuse of tyres, mainly for the purpose they have been manufactured for and for utilisation in other useful applications, product reuse has its limitations.

After tyres cannot be reused anymore, waste management alternatives such as material recycling and energy recovery play significant role in the scrap tyre management. From environmental point of view, material recycling is a preferred option. It allows recovery of materials and energy. However, lack of markets for the recycled rubber products, often caused by their lower quality, are the main causes of lower economic feasibility of material recovery. The recovery of the energy content of tyres is a promising route available for management of post consumed tyres, especially until recycling of tyres is more feasible.

6. Waste tyre management pattern in Europe

Being aware of potential environmental problems related to improper waste tyre management, the European Union has started the process of developing integrative environmentally sustainable waste strategy for used tyres. In response to evolving initiatives, several Member States and more progressive accession countries have already taken actions to improve their waste tyre management practices. Some countries, however, are far more advanced from the others.

This chapter presents an overview on the current waste tyre management practices in Europe. It describes situation in selected European countries, including total volumes of used tyre arisings, share of individual management routes and relevant national policies. Additionally, this chapter identifies the most common trends and developments in waste tyre management within Europe.

6.1 Situation in selected European countries

For each country, the most recent available statistic data on the total volumes of used tyres generated and share of individual waste management alternatives are provided. Further, the most outstanding used tyre management practices including policy frameworks, industry initiatives, efficient collection systems and other practices applied on national levels are discussed. A brief overview on waste tyre management practices in selected countries of Europe is provided in Table 6.1.

The data presented within this section was obtained via personal communication with relevant national and international authorities (the list of interviewed persons is presented in Appendix I). In case of France, Germany, Italy and the United Kingdom, the officially published data was used (BLIC, 1997). In some countries, where updated figures were not available, other literature sources were used.

6.1.1 Austria

Annually, there are about 45 000 tonnes of tyres discarded in Austria. The main recovery route for generated waste tyres is incineration in the cement kilns which has shown, though, minor decline during the last few years. In 1993, approximately 70% of used tyres were burned in the cement kilns, whereas today, it is about 56 %.

At present, there are four cement kilns combusting waste tyres using different technologies; one of the kilns burns halved tyres; other plant incinerates whole tyres without steel rims, the last two plants are using shredded tyres with a size of about 10 cm. In average, burned tyres deliver approximately 5.4% of thermal energy input.

Table 6.1 Waste tyre management in selected European countries

Country	Volume (tonnes)	Percentage of total volume processed by individual options: Retread	Material reuse	Material recovery	Energy recovery	Landfill	Export	Policy highlights	Targets
Austria	45 000	-	-	-	56	-	-	• product tax, by legislation (1.1 ECU/car, 3.7-7.4 ECU/truck)	
Belgium	70 000	11	8	14	25	42	.	• voluntary agreements in Brussels and Wallony regions • in preparation: legislation	
Czech Republic	60 000	27	5	8	25	35	.	• ban on landfill (1998) • producer liability as take back obligation (1998)	• no targets
Denmark	19 000[1]	26	8	14	9	49	0.5	• voluntary agreement, take back obligation (1995) • product tax, Statutory Order (1.1 ECU/new, 0.5 ECU retreads) • collection system, collection rate 92% • ban on landfill of combustible waste (1997)	• recover 80% by 1997 • recycle 100% by 2002
France	375 000	20	8	8	15	49	.	• in preparation: legislation, producer liability, vol. agreements	
Germany	600 000	20	.	14	45	21	.	• Act on Avoidance Recycling and Disposal of Waste (1994) • producer liability • disposal charge, industry (4.2-7.8 ECU/tyre) • voluntary agreement on end of life vehicles	• recover 80% by 1997 • recover 100% by 1998 • *priorities:incineration, powder, pyrolysis,*
Hungary	45 000	11	.	9	0	78[2]	2	• product charge, in Decree (new, for retreading: 0.1 ECU/ kg; 0.85 ECU/car, 3.1 ECU/truck; used: 0.6 ECU/kg; 7.2 ECU/car, 28 ECU/truck)	• no targets
Italy	260 000	22	.	15	23	40	.	• in preparation: legislation, producer liability	
Netherlands	65 000	37	.	8	32	0	23	• Rules for Collection and Disposal of Used Car Tyres (1995) • ban on landfill • producer liability as take back obligation • collection system • disposal charge on tyres, industry (1.2-1.6 ECU/tyre) • product charges on cars, in Environmental Management Act (69 ECU/car) • voluntary agreement on end of life vehicles	• reuse 60% by 2000 • mat. recovery 20% by 2000 • en. recovery 20% by 2000

Table 6.1 Waste tyre management in selected European countries—continues

Country	Volume (tonnes)	Percentage of total volume processed by individual options						Policy highlights	Targets
		Retread	Material reuse	Material recovery	Energy recovery	Landfill	Export		
Norway	33 000	4	.	.	42.5	43.5	10	• Regulations relating to the disposal, collection and recycling of discarded tyres (1995) • ban on landfill • producer liability as take back obligation • product charge, industry • collection system, collection rate 52%	
Slovakia	14 700	.	.	71[3]	10	19	.	• product charge, industry	
Spain	139 000	25	8	9	1	58	.		
Switzerland	50 000	10	-	.	34	15[4]	41	• product fee on voluntary basis (1.2 ECU/car , 4.3 ECU/truck) • ban on landfill of combustible waste (2000)	
Sweden	60 000	5	6.5	12.5	64	5	7	• Ordinance SFS 1994:1236 (1994) • producer liability • voluntary agreement • product charge, industry (1.5 ECU/car ; 9.1 ECU/truck) • collection system, collection rate 90%	• recovery 60% by 1996 • recovery 80% by 1998 • recovery 100% by 2000 • *priorities: reuse, recycle, use as a fuel*
UK	370 000	31	5	11	27	26	.	• Government Producer Responsibility Challenge (1994) • producer liability • voluntary approach • landfill tax (10.5ECU/tonne of tyres) • collection system, collection rate 74%	• prevention 10% by 2000 • retreading 25% by 2000 • recovery 65% by 2000

[1] only tyres for motorcycles, cars and vans; [2] landfill, littering, storing; [3] retreading, material reuse and recovery; [4] unknown; - data not available

In Austria, all cement kilns including operations which use conventional fuels, used tyres and rubber waste are regulated by *Regulation of the Federal Ministry of Agriculture for Air Emission Limits in Cement Kilns (BGBI No. 63/1993*) which falls under mining laws. According to the Regulation, the emission limits for particulates are 50 mg/m^3, for SO_2 200 mg/m^3 and 500 mg/m^3 for NO_2. The incineration of other waste is not regulated by the same regulation but individually by other competent authorities. The special regulation for the incineration of tyres in the cement kiln is due to the fact that the Austrian cement industry has been using the thermal input of tyres since 1979 successfully (Roubin, 1998).

In 1987, the country introduced product tax which is levied on the new tyres. For car tyres the charge is 1.1 ECU (15 ATS) and 3.7-7.4 ECU (50-100ATS) for truck tyres. The revenues serve for financing of the tyre collection system and incineration. Furthermore, disposal fees are collected when used tyres are disposed, e.g. at car repair shops. Exact figures on disposal fee, which vary locally, are not currently available.

6.1.2 The Czech Republic

Until recently, landfilling has been the most common option for waste tyre disposal in the Czech Republic. This undesirable situation is expected to change significantly since the new legislation introducing ban on landfill and take back obligation (producer liability) came into force in 1998. The Czech waste tyre management is described in more details in Chapter 7.

6.1.3 Denmark

According to information provided by the Ministry of Environment and Energy of Denmark, total volume of 1997 post consumed tyre arising in Denmark was 19 000 tonnes. However, these data include only tyres for motorcycles, cars and vans. Data on lorries, buses, industrial and agricultural vehicles are not included because their statistics does not exist since a return system for these tyres was not established (ME Denmark, 1998). The Agency reports 92% collection for used tyres from which 26% is retreaded or directly reused; remaining 73% is recovered.

Although in 1991, approximately 50% of total tyre volume generated in the country was disposed of by landfill, landfilling has already dropped to zero since charges for this disposal route have been increased and differentiated favouring incineration with energy recovery. Furthermore, the ban on landfill for combustible waste was introduced in 1997 (COM/95/624 final).

The Danish legislation dealing comprehensively with the tyre waste management was enacted in 1995 when association representing producers, importers, retailers and the recycling industry signed a voluntary agreement with the Minister for Environment and Energy. The agreement placed the association under the obligation to reach a collection rate of 80% by the year 1997 a obligation to take back discarded tyres. Furthermore, the agreement sets out the administrative role of the association.

In connection to the agreement, a Statutory Order has been issued. In accordance with the Order the importers and producers of tyres shall pay a levy of 1.1 ECU (8 DKK) to the Ministry of Environment and Energy when selling new and reusable tyres and a fee of 0.5

ECU (4 DKK) when selling retreads. Collectors of tyres (about 60) get a premium of 163.3 ECU (1 200 DKK) per tonne of tyres delivered to companies producing rubber powder from the tyres. The collectors pay a disposal fee of 95.3 ECU (700 DKK) per tonne delivered to the company receiving the tyres for production of rubber crumb.

Private sector is responsible for the program. The governmental bodies participate only as observers. The revenues from collecting the fee are used to finance collection, sorting and recycling of tyres and administration of the program. The money are disbursed to companies which are dedicated to tyre recycling on the basis of approved budgets and business plans. The agreement is a joint declaration between those involved in the manufacture, sales, servicing and processing of tyres and public authorities.

6.1.4 Finland

Environmental legislation which includes consideration of used tyre disposal was enacted in 1996. According to the legislation, recycling of used tyres is the priority. Governmental financial supporting for the system was not introduced. Collection of tyres is organised by two private companies *Sakkivaline* and *Suomen Rengaskierrarys*, which established a network of regional collection sites. The main target of these companies is to double the amount of collected tyre within one year.

6.1.5 France

Approximately 18% of total volume of generated used tyres in the country are exported, mostly to Belgium and UK. The disposal of the remaining annual volume, about 375 000 tonnes, is largely dependent upon landfills (49%) and cement kilns (15%). The relatively small share of energy recovery is not surprising considering the country has some of the lowest electricity costs in Europe. The disposal fee for the cement kiln varies between 12.7 and 46.4 ECU (300-800 FF). Material recovery practices represent 16% of the post consumed tyre processing. About 20% of the used tyres are retreaded (Phare, 1997).

Legislation and voluntary agreements in which the manufacturers would be held responsible for their waste were proposed but the details have not yet been finalised. In two areas, regional strategies have been developed; however, these have more in common with regions in other countries than with the national plan.

6.1.6 Germany

Annual used tyre generation in Germany is estimated for about 600 000 tonnes. Most of the generated used tyres, about 45%, are processed in the cement kilns. Currently, there are up to 30 cement kilns using tyres as alternative fuel. This number is expected to decrease dramatically because of a law bringing in new emissions controls. Relatively high volumes of discarded tyres (14%) are recovered while the obtained material is recycled. To ensure a standard quality for obtained end products, tyre recyclers are required to be certified in accordance with ISO 9 000. Development of material and energy recovery practices in the country has contributed to substantial decrease of landfill from 32% in 1991 to 21% in 1996 (Annex IX).

Germany is one of the main exporters of used tyres in Europe. In 1996, the export amounted about 56 000 tonnes of tyres. Significant streams of partly worn tyres are exported to Africa and Eastern Europe mainly for their direct reuse and retreading (UNCTAD, 1996).

Since 1991, the collection system for used tyres have been working in Germany, administrated by *Gesellshaft fur Altgummi-Verwerstugs Systeme GmBH (GAVS)* which is an association of rubber and tyre manufacturers, retailers and retreaders. At present, the tyre dealers in each state charge a disposal fee according to the market which causes wide variations from 4.2 ECU (8 DM) to 4.8 ECU (15 DM). Only a fraction of the fee is passed on to the recyclers.

Enacted in July 1995, *Act on the Avoidance, Recycling and Disposal of Wastes,* which comprises both the Product Recycling and Waste Management Acts intends to implement product recycling on the basis of a comprehensive production and product responsibility. Tyre recycling is included under Article 14 of the law.

In addition, a voluntary self imposed obligation for environmentally friendly recovery of end of life vehicles was enacted in 1996 within the framework of the law on recycling industry. Based on this, the sectors involved committed themselves to:

- Ensure dismantling and recovery of parts and materials from end-of-life vehicles, including used tyres;
- Reduce the amount of waste to be removed from its present average level of 25% of the weight of an end-of-life vehicle to 15% of the weight by 2002, and to 5% of the weight by 2015;
- Submit to the Ministry of Environment and the Ministry of Trade and Industry every two years a report concerning the implementation of the voluntary obligation.

6.1.7 Hungary

Approximately 45 000 tonnes of used tyres are generated per year in the country. A rather high amount of landfilling (about 78%) includes traditional disposing by landfills, littering in forests and rivers, and also storing for future reuse or recovery. Further, about 11% of post consumed tyres is retreaded, 9% grinded and 2% exported mostly to Ukraine. Based on he information obtained, in Hungary scrap tyres are not incinerated in cement kilns or in fuel boilers.

In 1995, Hungary passed *Decree of the Minister of Environment and Regional Policy 10/1995 on Product Charges and the Environmental Protection Product Charges of Certain Products* which addressed waste tyre issues. The Hungarian product charge legislation aimed to address the environmental problems originating from the disposal of solid waste coming from a variety of products.

The tyre product charge is levied on domestically produced and imported automobile and truck tyres. The basis of the product charge is the weight of the tyre. For new tyres and used tyres imported exclusively for retreading, the charge is 0.13 ECU/ kg (30 HUF/kg), i.e. about 0.85 ECU (200 HUF) per car tyre and 3.1 ECU (720 HUF) per truck tyre. For used tyres and retreaded imported tyres, the charge is 0.6 ECU/ kg (120 HUF/kg), i.e. 7.2 ECU

(1 700 HUF) per car tyre and 28 ECU (6 600 HUF) per truck tyre. The product charges are paid to the Central Environmental Protection Fund from which about 75% is earmarked for the scrap tyre problem covering administrative expenses.

6.1.8 Italy

Based on the information provided by the *Assogomma*, association for tyre producers, Italy generates about 260 000 used tyres per year. Italy has a very successful retreading industry, represented mostly by *Maragonni*, while the statistics shows that about 22% of post consumed tyres are retreaded.

Nevertheless, approximately 40% of generated used tyres are still disposed of by landfill; however, this disposal route is in essence declining compared to 51% in 1991 (see Appendix IX). Further decrease is expected because of general encouragement of energy recovery options, including incineration of tyres in cement kilns and retreading plants in the last few years.

At present, the country does not have any national waste tyre policy. It is expected that several effective policy instruments, such as producer liability, will be included in the new waste act which is currently under preparation (Assogomma, 1998). Besides, several Italian regions have already taken actions and established tyre collection systems which are nationally administrated by the Consortium ECO.PNE.US. This association is responsible for certification of selected tyre collectors according to ISO 9 000; further, it provides monitoring and information dissemination of available tyre recycling processes in the country.

6.1.9 The Netherlands

The Netherlands belongs to the European countries with the most progressive and advanced system for waste tyre management. Thanks to the ban on landfill introduced in 1996, the country has managed to decrease tyre landfilling from 50% to 0% of total 65000 arisings within a few years. Currently, a large number of used tyres is exported for direct reuse, retreading and incineration in the cement kilns. More detailed information on the Dutch waste tyre management practices are provided in Chapter 7.

6.1.10 Norway

The total volume of used tyres generated annually in Norway is 33 000 tonnes. From this amount, some 3 000 tonnes are exported and 30 000 tonnes are available for collection. According to the Norwegian Pollution Control Authority, the collection rate is 52%. From this amount, about 5% is retreaded and 47% is shredded and incinerated in the cement kilns. Since no tyres are collected for recycling, it can be assumed that the remaining 48% is disposed of by landfill. The percentage share given in Table 6.1 is related to the total annual arisings, e.g. 33 000 tonnes of tyres.

Regulations relating to the disposal, collection and recycling of discarded tyres came into force in January 1995. These govern tyres for passenger cars, delivery vans, busses, lorries and motorcycles, and include the ban on landfill and the producer liability defined as take back obligation. According to the regulation, the tyre manufacturers and importers are obliged to collect discarded tyres without charge. The collection system of Norway is similar to that of Sweden, financed by the product charges levied on new products (Ministry of Environment of Norway, 1995; Norwegian Pollution Control Authority, 1998).

6.1.11 Slovakia

According to information provided by the Ministry of Environment of the Slovak Republic, the amount of tyres discarded in 1995 totals 14 700 tonnes. From this amount, rather significant quantity, about 71%, destines for material recovery. However, it should be pointed out that this share includes retreading, direct reuse, material reuse and recycling. More detailed data on selected processing options is not available. About 10% of the tyre stream is incinerated in the cement kilns, which purchase tyres as an alternative fuel. The price of tyres destined for combustion equals to the price of all alternative fuels, which is 300 SKK per one tonne. Remaining 19% of tyre arising is disposed in landfills.

Import of tyres to Slovakia is regulated. In 1995, the officially permitted import amounted 5 000 tonnes. The volume decreased to 3 600 tonnes in 1996. Although these are official statistic data, according to the authorities it is expected that the overall import is by 30-40% higher.

Similar as in the case of the Czech Republic, a state owned company *Zberné suroviny* (Collected Raw Materials) organised the collection of used tyres before 1989. However, this collection was not efficient and after the political changes its efficiency even decreased. In 1995, a new collection system was established in a co-operation with the national tyre producer *Matador.* The new collection system, covering the whole country, is organised by Matador retailers. These collect tyres from the consumers free of charge. The product charge, set by Matador, is included in the price of a new tyre; it is charged when a new tyre is purchased.

Collected tyres are sorted in the collection nodes from where these are distributed for further processing. Worn out tyres are granulated in the branch of Matador, *Matador Eco,* which is the only tyre grinding company in the country. Establishment of the company was subsidised by the Environmental Protection Fund. Fine granulate is used as a filler in tyre tubes manufactured by Matador. Involvement of the tyre producer in the whole life cycle of tyres is a part of a new environmental image that the company is building. Additionally, waste tyres generated in Bratislava region are collected by *ASO* company, which delivers them to the cement kiln *Hirocem* in Rohožník.

6.1.12 Switzerland

Based on the information provided by the Swiss Agency for the Environment, Forests and Landscape, Switzerland generated about 50 000 tonnes of used tyres in 1996. From this amount a significant volume of 41% was exported. However, the export declined substantially compared to year 1991 when it represented almost 60%. In contrast, the recovery of tyres in cement kilns increased from 30% in 1991 to 34% in 1996. The predictions prepared by the Agency for the year 2 000 expect an additional increase of energy recovery in cement kilns to 50%. In 1996, approximately 10% was retreaded and 15% represents amount for which the actual means of processing is not available but can comprise of landfill or material recovery routes.

Switzerland has recently passed a law which includes a ban on landfill of combustible material (including tyres). The applicability of the ban starts from January 2000. Although several literature sources mention that product tax has been introduced also in Switzerland, the country does not have official tax on sold tyres. The fee of 1.2 ECU (2 CHF) per car tyres and 4.3 ECU (7 CHF) per truck tyres is charged by members of *Reifen-Verband der Schweiz* association on a voluntary basis. The association serves as an administrator of collection system developed in Switzerland. Several tyre producers collect the tax and take back used tyres free of charge from their retailers.

6.1.13 Sweden

Based on the information obtained from the national authorities, Sweden generates about 60 000 tonnes of post consumed tyres per annum. Due to a well established collection system, the collection rate of discarded tyres has recently reached nearly 90%. From this volume, about 5% of tyre arisings are retreaded. The export represents up to 7%. An area that is increasing in size is material recycling amounting 12.5%. Reuse of whole tyres represents 6.5%.

The most important area of application today is the energy recovery which amounts approximately 65% of the total annual arising. From this amount, about 50% is recovered in one cement kiln incinerating shredded tyres. This significantly high energy recovery rate places Sweden among the European leaders in this processing alternative. Additionally, Sweden is one of the leading importers of tyre related rubber waste in Europe, which is mainly destined for energy recovery. Although the country achieved high collection ratio and has well established post consumed tyre management, about 5% of used tyres are still disposed of by landfill.

In 1994, the Swedish government prepared *Ordinance SFS 1994:1236* which provided framework for the producer liability. The body responsible for implementing the new legislation is a non-profit organisation, *Svensk Dackatervinnning AB (SDAB)*. The principals of the company are the Swedish Association of Tyre Suppliers and the Swedish Federation of Tyre Specialists. The roles of SDAB include financing, administration and reporting to the Swedish Environmental Protection Agency. It also supports research and development work in the area of tyre recycling. The Swedish EPA serves as the central supervisory authority which monitors the situation.

SDAB has a contract with the tyre suppliers that requires them to charge a product charge (15 ECU for cars, 75 ECU for trucks) for each new tyre sold. The suppliers charge their retailers and the retailers charge the end consumer. The tyre suppliers are responsible for collecting the information, reporting quarterly their statistics to SDAB and remitting the fees they collected. All retailers or anyone who has scrap tyres can leave them at collection points around Sweden free of charge. The collection, handling, sorting, storage and disposal is done by one main contractor which established a network of collection sites (93 drop off points) covering the whole country (SDAB, 1998).

6.1.14 United Kingdom

The United Kingdom generates annually about 370 000 tonnes of used tyres. From this amount, approximately 31% are retreaded, 16% recycled, 27% recovered for energy and 26% landfilled. The present recovery rate of 74% indicates that UK is on track to achieve the EU targets presented in 1993 (COM/XI/454/93-EN). The current waste tyre processing pattern shows a significant improvement over the situation reported in 1991 when about 52% of arisings were landfilled (see Annex IX).

The large decline in landfilling is due to the operation of the *Elm Energy* tyres to electricity plant at Wolverhampton which has been working at near full capacity since June 1995, accounting for some 15% of used tyre arisings. Additionally, the cement manufactures have shown the growing interest in waste tyres as a fuel. Furthermore, retreading as well as material recovery have shown a significant increase during the last years.

In 1995, the *Industry Scrap Tyre Working Group (STWG)* made up of representatives of industry, trade associations and government was set up in response to a government request that the producers for waste should take responsibility for their waste. The STWG's main tasks have been to improve scrap tyre statistics, monitor retread and recovery rates, and facilitate the emergence of new projects. The industry members of the STWG are continuously encouraging their member companies to take voluntary actions to increase their responsibility for scrap tyre disposal.

The UK waste tyre legislation includes three main policy instruments: the producer liability, the landfill tax and the requirements on import of used tyres. The producer liability was introduced in 1994 in *Government's Producer Responsibility Challenge*. The landfill tax of 10.5 ECU (7L) per tonne of tyres was adopted in 1996 in order to encourage the business to look more closely at the recovery and recycling. The requirements on import came into force in 1995 by *Department of Transport's Motor Vehicle Tyres Safety Regulations*, requiring that second hand tyres be fully tested before sale and marked to show they are part-worn. This regulation is aimed to regulate the import of unsafe used tyres for resale. The import of part worn tyres in 1995 was 29 000 tonnes (STWG, 1996).

6.2 Conclusions on management pattern in Europe

Based on the above provided description of used tyre management practices in selected European countries, it appears that many countries took progressive measures to deal with the used tyre arisings. Although the practices in individual countries differ, the following trends seem to be evolving overall in Europe.

Policy involvement: A number of European countries have undertaken legislative initiatives towards sustainability in rubber and tyre industry. The most common policy instruments applied in the waste tyre management include the ban on landfill, the producer liability often specified as take back obligation on both used tyres and end of life vehicles. Several countries have set up their targets within the national policies. Additionally, voluntary agreements involving governments and industries have already proved to be effective in several European countries, such the Netherlands and Germany.

Establishment of a collection system: Collection is one of the first actions to be taken in order to prevent waste to be disposed off. Recovery and recycling cannot be performed without a proper collection network aimed to optimise sorting and distribution of collected materials. Although in many countries the collection system has not been developed and well structured yet, the current trends show that more advanced European countries, such as Denmark, Germany, the Netherlands, Norway and Sweden has taken essential measures to collect used tyres more efficiently.

The collection system is financed either by *product charges* included in the price of new tyres or by *recycling fee* charged when a tyre is collected. Product charges are set either legislatively (Denmark, Hungary and partly the Netherlands) or by industry (Norway, Slovakia and Sweden). Recycling fee is in all cases driven by market (Germany, the United Kingdom, partly the Netherlands). The establishment of collection systems is frequently supported by nationally set targets.

Reduction of landfill: The prohibition of landfill adopted in several countries, increasing cost of landfilling and the appreciation of tyre rubber as a clean fuel seem to push waste tyre routes from undesirable dumping and dispersion to energy recovery. If this trend continues, the termination of the disposal on land can be foreseen in a few years which will have a positive impact on scrap tyre management in Europe.

Recovery of used tyres: Recovery of waste is at the core of any sustainable waste management policy. Material and energy recovery, is an important target set by the EU and countries with advanced environmental policies. At the national level, different countries have adopted legislation aiming to implement the reuse of pneumatic tyres in different ways. It can be anticipated that the industrial consolidation of new cost effective technologies will contribute to shift recovery partially from energy to material recovery. One important option appears to be retreading of used tyres.

7. Case study

The objective of this chapter is to provide more detailed overview of the current situation in management of post consumed tyres and tyre related rubber waste in two countries with different waste tyre management practices. For the purpose, two case study countries have been selected: the Czech Republic and the Netherlands. Waste tyre management in the Czech Republic is under transition driven by the process of approximation to the EU standards and strategies. The Netherlands represents the Member States with well established waste management practices considered to be a leader in this field.

This chapter presents the main characteristics of waste management concerning used tyres in the selected countries. For each country, the following issues are discussed and analysed: existing policy framework, collection system, disposal fee, configuration of processing options and trade. Finally, a comparison of the main findings is given. The data and information included in this case study have been obtained by interviews with relevant stakeholders in both case study countries (see Appendix I). In addition, available background literature has been used.

7.1 The Czech Republic

The Czech Republic has a rich tradition in rubber industry, including primary production, manufacturing of tyres and processing of rubber waste. As a result, the country has an extensive capacity for processing used tyres and rubber waste. The processing capacity appears to be even higher than the volumes of rubber waste produced on the national scale. This capacity has grown significantly especially with growth of the private sector but high operational costs, unstable supply of tyres, poor legislative support and low market possibilities for recycled materials remain problems.

This case study was elaborated in a critical period, which can be considered as transitional in relation to the subject. During this period, new legislation came into force which addressed the waste management issues in a new policy framework using policy instruments harmonised with the EU legislation.

7.1.1 Policy

Shortly after the political changes in 1989, the Czech Republic introduced its first *Waste Management Act (238/1991*). Before this period, the only legislation dealing marginally with waste management issues was the *Governmental Regulation on Management of Metal Scrap and Collection of Raw Materials (No. 68/1960)*. This regulation, however, did not specifically cover issues on management of post consumed tyres.

At the present, the main legislation relevant to processing of used tyres and tyre related rubber waste is the *Waste Management Act 125/1997*, which is in force since 1 January 1998. The Act sets out the framework for waste management strategy on the basis of EU standards. Furthermore, it introduces several new tools and instruments such as the ban on landfill and producer liability which are also the main instruments in the present Czech policy, with a possible direct impact on the processing options of used tyres and tyre related rubber waste. The current Czech policy on processing used tyres and tyre related rubber waste does not specify any targets.

Ban on landfill: Used tyres and tyre related rubber waste have been placed on the waste list to which prohibition on landfill implies. Considering that the ban on landfill is meant to encourage alternatives to final disposal, vague specification of waste producer obligations in the Act itself indirectly provides space for disposing tyres in landfills which can distort the implementation of the ban.

Decree which supplements the Waste Management Act of 1997 bans the landfill of tyres (Dec. 338/1997 art. 8). On the contrary, the Act itself obliges the waste producers "to permanently offer such waste which he is unable to use for utilisation to another natural or legal person" and "should it be impossible to use the waste he can secure final disposal" (Act No.125/97 Coll. Art. 5). Although, it is premature to evaluate the implementation level of this Act, it should be noted that the discrepancies within the legislation can have negative impacts on achieving the aims of the legislation.

Take back scheme (applied principle of producer liability): Another important instrument which has been introduced by the new waste legislation is take back scheme obligation (Act No.125/97 Coll.Art.19). The actual governmental regulation listing products to which the obligation applies has not been finalised yet. According to the interviews taken, used tyres and tyre related rubber waste will be most likely listed among the products to which the liability applies. Manufacturers of tyres are responsible to develop a take back scheme which will ensure used tyre collection. The legislation does not specify any economic instruments and targets which should be implemented by manufacturers of the products to which the liability applies .

Record and notification of waste processing: Collectors, dealers and processors of waste are obliged to prepare annual reports on the type, volume and methods of management of their waste (Act No.125/97 Coll.Art.20). It is expected that this instrument will contribute to make the processing of waste tyres more transparent which can have positive impacts on the tyre management.

Import and export of waste tyres: According to the national legislation, used tyres and rubber waste are on the yellow waste list, using OECD coding system, as items GK020 and GK030. The import and transit of wastes given on the yellow list are possible pending the fulfilment of notification liability (Dec. 337/1997). Considering that the Czech Republic has acceded the Basel Convention, the rules on import and export of tyres as they are specified in the Convention apply to the national policy.

The import of worn out tyres for the purpose of their disposal in the Czech Republic is banned. It is permitted only if tyres are imported for the purpose of material recovery. It is important to note that incineration with energy recovery is considered to be final disposal; therefore, import of tyres for this purpose is not allowed. Imported volumes of tyres for material recovery are regulated by setting up limits on imported volumes. These are set up by the authority and their aim is keeping a balance between processing of imported and domestically originated tyres. Commonly, for every imported tonne of tyres the importer is required to process one tonne of tyres from the national market.

7.1.2 Collection system

A missing collection system can be seen as the main weakness of the waste tyre management in the Czech Republic. Until 1989, a state owned company *Sběrné suroviny* (Collected Raw Materials) was responsible for collection, registration, separation and further delivery of used tyres for processing and final disposal. After the network of Sběrné suroviny was abandoned, it has not been replaced by any other collection system.

Nowadays, there is no efficient collection system for used tyres in the Czech Republic. As a consequence, a regular flow of used tyres from producers to processors within the country is missing which places tyres to rather contrary positions. On one hand, the garage holders consider used tyres to be waste which is inconvenient and expensive to be delivered for proper processing. Therefore, illegal dumping and other inexpensive waste management options, such as landfilling, appear as common disposal routes. In contrast, the processors see used tyres as a hardly available material which they often import from other countries while receiving higher compensation.

7.1.3 Disposal fee

Since disposal fee represents income for processing companies, the exact information is very difficult to obtain. Based on interviews, the current disposal fee is market driven and varies between 15 and 30 ECU per tonne of tyres for all processing options apart from incineration in the cement kilns where no disposal fee is charged. In general, the Czech disposal fee appears to be significantly lower compared to the Western European countries which drives the Czech processors to import tyres from abroad.

Further, the differences in level of disposal fee among individual options create environment for benefiting less desirable options, such as still performed landfilling. Generally low disposal fee has also negative impact on profitability of operators of recycling facilities.

7.1.4 Configuration of processing options

At present, there is no reliable source of information providing exact numbers of annually generated used tyres in the Czech Republic. The arising is estimated to be 50 000 to 60 000 tonnes of used tyres per year (Kreizlová, 1997). However, some of the interviewed stakeholders believe that this number can be even two times higher, especially when imported tyres are taken into account. Transparency of data on used tyres in the country is expected to be improved as a result of implemented Waste Management Act of 1997. According to this framework policy all waste generators, collectors and processors are required to inform the Ministry of Environment on the amount of generated and processed waste, including the processing routes.

Currently, all the most common waste tyre management technologies, apart from pyrolysis, are operating in the Czech Republic. Configuration of processing options in the Czech Republic is summarised in Table 7.1. Data included in the table is from available literature and interviews.

Table 7.1 Configuration of processing options in the Czech Republic

Option	Rubber waste in 1992 *tonnes of rubber*	*%*	Used tyres in 1997 *tonnes of used tyres*	*%*
Incineration	8 000	13	0	0
Incineration in cement kilns	0	0	15 000	25
Grinding & reclaiming	4 000	6	5 000	8
Storing	8 000	13	0	0
Landfilling	20 000	32	21 000	35
Retreading	0	0	16 000	27
Others	23 000	36	3 000	5
Total amount	63 000		6 0000	

Source: Nekvasil, 1996; Interviews, 1998

Retreading: Retreading of tyres has a long tradition in the Czech Republic. In the past, retreaded tyres were commonly used by consumers especially because of their low prices and relatively good image. Nowadays, there are approximately 30 retreaders operating in the country; the largest of them are *Obnova Brno* and *Mitas Prague*. Truck tyres are usually retreaded 1-2.5 times. It is estimated that approximately 10% of the retreaded tyres in the Czech Republic are exported, mostly to Germany.

Retreading in the Czech Republic faces problems in terms of large, unused capacity which has recently reached 50 %. Retreading companies do not have sufficient supply of used tyres and the market for retreaded tyres has declined as result of increasing consumers' demands.

In order to obtain retreadable casings, retreaders import part worn tyres. Some of the imported tyres are still matching the Czech standard of 1.6 mm of tread depth. These are sold for a short term direct reuse and soon they become waste disposed in the country. Similar problem arises when imported casings are not suitable for retreading anymore and become waste disposed in the Czech Republic.

The leading Czech tyre producer, *Barum Continental Otrokovice*, has recently introduced a retreading guarantee for tyres manufactured by Barum. The producer guarantees a number of kilometres which includes additional kilometres on retreads. If the tyre cannot be retreaded, as it was guaranteed, the producer reimburses the casing. This instrument was designed to promote a regular flow of retreadable casings from producers to retreaders within the country. Furthermore, the producer recommends consumers to use passenger car tyres with a tread depth at least 1.8 mm, although the Czech standard requires only 1.6 mm.

Physical applications: Reuse of tyres in physical applications plays a minor role in the Czech Republic. Used tyres are rarely applied in civil engineering works as highway crash barriers, sound absorbing walls, water protection barriers and temporary fences. More frequently, waste tyres are used as a construction material for landfills, especially for their base layer.

Grinding: At present, there are approximately 13 companies in the Czech Republic, providing either mechanical or cryogenic grinding. The most important granulation plants, their capacities, types of applied technologies and market for obtained products are listed in Appendix X.

All grinding companies in the country, apart from *Renogum Nilos* which has market for its products in Germany, are facing problems in terms of insufficient input supply and low market demand for output products. In order to increase the market possibilities for granulate, research and development are permanently carried out; however, the market applications for granulate are still extremely limited. For instance, *Kaučuk Kralupy* has developed a binding agent for granulate in tiles. *KAC* has patented an absorption material prepared from granulate. Research on application of rubber modified asphalt in road pavement is carried out by research institute *ITC Zlín*.

In 1994, the unsatisfactory position of granulation plants promoted establishment of the *Association of Tyre Recyclers*. Since then, the association has been lobbying for a legislative support of recycling activities. Product charges, recycling subsidies and other incentive based policy instruments are among the main issues raised by the Association of Tyre Recyclers. However, the recently adopted Waste Management Act, did not include any of these instruments but the liability and ban on landfill are relevant for granulation companies.

Production of granulate in the country is substantially higher than the actual demand. As a result of supply and demand ratio, prices of rubber granulates are about 50% lower than in neighbouring Western European countries. This situation is the driving force behind active trade with granulates. When exporting the granulate, the companies are facing the problem within HS system which classifies granulate as waste and not as final commodity.

Reclaiming: The reclaiming activities are represented mostly by the company *Eko-Rubber* (previous Eko-Barum) which has a long tradition in rubber recycling. Granulate supplied from the Czech and Slovak granulation plants, rubber crumb from retreading companies and whole truck tyres are processed in high pressure steam technology. Out of the total reclaim production, which is now approximately 6 000 tonnes per year, about 5 000 tonnes are sold to rubber processing companies on the national market or exported to the Slovak Republic, Sweden, UK, Germany and the Netherlands. The remaining 1 000 tonnes of reclaim are used for production of final products, such as small agricultural wheels, road retarders and waste baskets.

The reclaim production in the country has decreased by 50 per cent compared to 1991 when the total annual output volume reached 15 000 tonnes (Kreizlová, 1997). The declining market for reclaim has been caused by increasing quality demands for rubber in the final products.

Incineration in cement kilns: Since the early 80’s, scrap tyres have been processed in cement kilns in the Czech Republic. Nowadays, there are two cement kilns using tyres as supplementary fuel. The total volumes of incinerated tyres and leading tyre suppliers are presented in Table 7.2.

Table 7.2 Cement kilns using tyres as a fuel

Cement kiln	Incinerated amount in 1997 (tonnes)	Tyre supplier
Cementárna Mokrá	13 000	TASY Brno
Cementárna Čížkovice	2 400	JOKR Čížkovice

Source: Interviews, 1998

In the *Cement kiln Mokrá*, which operates two rotary kilns, used tyres have been incinerated since 1983. Special filling equipment for tyres was installed in 1995. One of the reasons for incineration of tyres in the cement kiln was a replacement of natural gas which was then used for gasification of the local area. Although the Cement kiln Mokrá is permitted to incinerate used tyres up to 20% of the total fuel input, it actually incinerates only 9%. The kiln does not use its permitted capacity as a result of insufficient supply of scrap tyres. Compared to the granulators, the cement kiln has been more successful in obtaining tyres so far. Until 1997, the cement kiln was purchasing tyres from its supplier. Today, it receives tyres mainly free of charge.

In relation to the current legislation, import of used tyres for the processing in cement kilns, can become more difficult. According to the present interpretation of the waste law, the import of waste for final disposal, including incineration with energy recovery, is prohibited.

Landfilling and monofilling: Until recently, landfilling was a common disposal option for used tyres and tyre related rubber waste. The amount of used tyres disposed of in landfills has reached at least 10 000 tonnes per annum (Kreizlová, 1997). The main reason for the preference of this practice was easy access to a number of landfills with low disposal fee (4 ECU per tonne of tyres) compared to significantly higher recycling fee (28 ECU per tonne of tyres).

The amount of landfilled tyres is expected to fall dramatically as a result of newly introduced ban on landfill. This should promote use, ultimately economic feasibility and profitability, of alternative processing options.

Based on the interviews, the ban on landfill has not proved to bring the expected results. Even though the operators of landfills claim that tyres are not landfilled any more, the waste processors have not noticed any increase in volumes available for other disposal options. To ensure faster implementation of the ban, more clear juridical formulation in the Waste Management Act and imposing of stricter control will be necessary.

Pyrolysis: Currently, there is no pyrolytic facility processing scrap tyres in the Czech Republic. However, *Škoda Klatovy*, a major producer of heavy machinery, together with American company *Titan Technology* have already presented an investment plan to build a pyrolytic unit with annual capacity of 20 000 tonnes of used tyres.

7.1.5 Trade

Based on statistic data provided by the *General Directorate of Costumes of the Czech Republic*, Figure 7.1 presents export and import pattern of used tyres and rubber waste in the period from 1993 till 1996 for the Czech Republic. More detailed overview of the main trade flows determining countries of origin and destination respectively is summarised in Appendix XI.

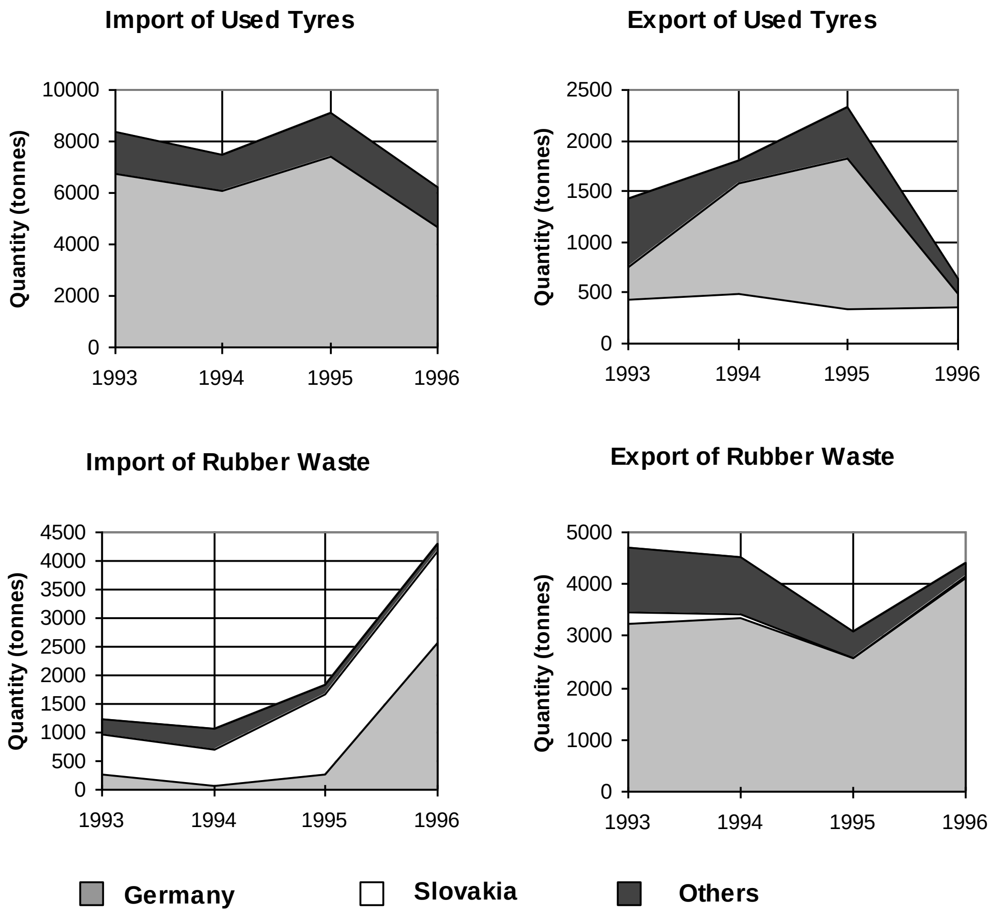


Figure 7.1 Export and import of used tyres and rubber by the Czech Republic

The total volume of import and export in used tyres has a declining tendency; whereas, import in rubber waste has increased by 75%. In terms of total volumes traded, import of used tyres used to be of the biggest significance. However, the data for 1997 show that the import of used tyres and rubber waste reaches comparable volumes in this particular year which may be expected future trend. As far as the export is concerned, the export of used tyres is marginal compared to the volumes imported while the export of rubber waste appears to be of significance.

Used tyres are imported to the Czech Republic mainly from Germany (about 6 000 tonnes). Additionally, considerable amounts, up to 1 000 tonnes per year are imported from neighbouring countries such as Austria, Poland and Slovakia. These are either reused directly or retreaded. A couple of years ago, large volumes were imported from Switzerland (485 tonnes in 1993); however, this import has notably declining tendency. In contrast, import from the Netherlands is growing. It is interesting, that most of the used tyres are exported to other Eastern European countries, mainly to the Slovak Republic (up to 500 tonnes per year), Ukraine, Poland or Russia and other independent countries of former Soviet Union and Africa (Appendix XI).

Germany and Slovakia are the main actors in import of rubber waste. By the end of 1996, the overall annual import of rubber waste was lower (1 800 tonnes) than the actual export

(3 000 tonnes). However, this pattern appears to be changing when looking at the 1997 data when the import is by 65% larger than the export (4 653 tonnes). Rubber waste is exported mainly to Western Europe, countries such as Germany, the Netherlands and Belgium (Appendix XI).

Trade plays an important role in management of tyres in the Czech Republic. Processing companies import used tyres and tyre related rubber waste in order to overcome insufficient domestic supply. Higher disposal fee in Western part of Europe is another driving force for trade. As a result, import is favoured among waste processors in Eastern Europe.

7.2 The Netherlands

The Netherlands is one of the leaders in Europe which displayed increasing concern over the management of post consumed tyres over the past years. The country has a well established tyre production and extensive capacities for used tyre processing. The policy framework related to the subject supports environmentally sound processing options such as product reuse and material recovery.

7.2.1 Policy

By the late 80's, the most common processing options of used tyres in the Netherlands were landfilling (53% in the year 1991) and incineration. The reuse and material recycling of scrap tyres and other rubber waste were marginal. The whole disposal system of waste, in general, was diffused and not controlled. In response to the undesirable situation, the Dutch Ministry of Environment (VROM) established a working group which evaluated the situation and identified 29 priority waste streams, including used passenger car tyres. In 1988, the priority waste streams were presented to the Dutch parliament in *Memorandum concerning prevention and recycling of waste materials*. In the following years, the waste management strategy was elaborated in the *National Environment Plan*.

In 1991, an *Implementation Plan for Used Tyres* was prepared. The preparation of the plan involved both industry and public authorities that presented the situation aimed for the year 2000 and described a system according to which parties should proceed. Six months after its approval, the parties disagreed and refused to take the necessary actions. The proposal based solely on voluntary agreements did not prove to be effective.

In response, the Ministry of Environment has prepared a more strict set of legislation which forms the current Dutch policy framework for the used tyre management. The most important instruments applied in the Dutch policy are:

- Targets;
- Ban on landfill;
- Producer liability, take back obligation;
- Voluntary agreements.

A full implementation of these policy instruments has contributed to establishment of an effective collection system which forms an important basis for waste tyre management in the Netherlands.

Targets: The targets for the year 2000 are specified in the *Rules for Collection and Disposal of Used Tyres* which came into force in 1995. They provide a core of the legal framework for used tyre management. The set targets have ultimately encouraged the actors to participate in voluntary agreements. The targets for individual processing options are presented in Table *7.3*.

Table 7.3 Targets for tyre management

Option	Target
Product reuse	60 %
Material recovery	20 %
Energy recovery	20 %
Landfilling	0 %

Source: VROM, 1998

Ban on landfill: The Netherlands was one of the first European countries which has prohibited landfill of post consumed tyres and rubber waste. Ban on landfill was introduced into the Dutch legislation in 1996. According to the official information provided by the Ministry of Environment, the ban on landfill of used tyres has been already fully implemented in the Netherlands. At present, the country is actively involved in introducing a ban on landfill at EU level.

Take back scheme (applied principle of producer liability): In 1995, the producer liability for end of life vehicles and for used passenger car tyres defined as take back obligation has been introduced in *Rules for Collection and Disposal of Used Car Tyres*. According to this legislation, there are two groups of actors responsible for the life cycle of car tyres: car producers and car importers, and tyre producers and tyre importers. Based on this legislation, the actors were encourages to establish a collection system for passenger car tyres.

Voluntary agreements (covenants): The target and the producer liability included in the Dutch legislative framework have encouraged car and tyre manufacturers and tyre processors to participate in voluntary agreement with the governmental institutions and public authorities. At present, covenants are widely applied in the Netherlands.

7.2.2 Collection system

One of the main strengths of the Dutch used tyre management is a well working collection. The collection system was developed by joint efforts of involved actors and implementation of the above mentioned policy instruments. It consists of two parallel collection systems:

- Dismantling collection system (organised by car producers and car importers);
- Replacement collection system (organised by tyre producers and tyre importers).

The collection is built on market mechanism principles. In the Netherlands, there is no special collection system designed for used truck tyres since these are collected directly by truck tyre dealers.

Dismantling collection system: In 1995, car producers and car importers designed a dismantling collection system for car wrecks including the used tyres from scraped cars. The system was established in order to ensure that by the year 2 000 at least 86% of the weight of the car constituent materials would be recycled (the target set by the automobile industry itself). The dismantling collection system is administered by *Autorecycling Netherlands BV (ARN)*, an association with a nation wide network of 275 licensed car dismantling companies. These companies are responsible for selection of dismantled components for proper further processing. By recycling approximately 90% of cars in an environmentally responsible way, the dismantling companies have already achieved the set aim.

The dismantling system is financed by an earmarked fund which has its income from the product charge (disposal fee, scrapping levy are terms used by authorities) included in the price of a new car. The waste disposal fee is declared by the *Environmental Management Act* as generally binding. The Ministry of Environment has initially set a fee of 115 ECU (250 NLG) for the period from 1 January 1995 to 31 December 1997. Because of the success of the dismantling collection system, in 1 January 1998, the waste disposal fee has been reduced to 69 ECU (150 NLG) for the coming three year period.

For the coming period, the ARN intends to continue the unchanged policy covered by the generally binding declaration with a new aim regarding the post 2 000 period. Determination of the new tasks will have to be influenced by a more precise definition of recycling and the part played in recycling by various high grade recycling techniques, considering both environmental and cost factors.

As concerns tyres, approximately 5 300 tonnes of post consumed car tyres were collected by ARN in 1996. From this amount, 65% was reused via direct reuse mostly in Germany, Poland, Russia and via retreading in the Netherlands, UK and Germany. Approximately, 5% was recycled in grinding companies within the Netherlands and 60% was burnt with energy recovery predominantly in the cement kilns in Belgium and Germany, partly in the cement kiln and waste incineration plant in the Netherlands (*Table 7.4*). Since the data was not officially published by ARN, it should be considered as estimates.

Table 7.4 Processing of car tyres collected within the dismantling collection system

Option	Percentage	Location
Product reuse	35	
• direct reuse		• the Netherlands, UK, Germany
• retreading		• Germany, Poland, Russia
Material recovery	5	• the Netherlands
Energy recovery	60	
• cement kiln		• mostly Belgium, Germany
• cement kiln, incinerator		• the Netherlands
Collected tyres	5 300 tonnes	• the Netherlands

Source: Estimates based on the interview with ARN, 1998

Replacement collection system: The system, designed by the tyre producers and tyre importers, is administrated by *Band & Milieu (BEM)* which associates 20 certified collectors. The replacement collection system is not financially supported by any additional fund.

Consumers bring used tyres to retailers who charge approximately 1.2-1.6 ECU (2.50-3.50 NLG) per a tyre. Although the fee is not set legislatively, the amount varies based on the market conditions, the Dutch consumers are willing to pay for a safe disposal of their tyres. Collected tyres are then offered by retailers to the certified collectors who identify tyres suitable for direct reuse, retreading, material recycling or energy recovery. Based on the volumes suitable for individual processing routes, collectors either pay or get paid for these tyres. Finally, collectors deliver tyres to processing companies. The prices of used tyres are set through negotiations between retailers and collectors, and collectors and processors.

Within the replacement collection system, BEM plays the following roles:

- Initiates certification of collectors (on the basis of ISO 9000);
- Ensures that collectors fulfil the requirements for certification;
- Guarantees a proper treatment of collected used tyres, including all the legal aspects;
- Ensures a continuity for the retailers;
- Initiates public campaigns and makes certified collectors as well as retailers to be publicly recognised (via a special logo and information in media);
- Requires the collectors to report the figures on collected tyres via external accountants;
- Provides information to the Ministry of Environment, including a yearly monitoring on the total figures, reporting the bottlenecks of the system and proposing improvement measures.

BEM claims to collect 75% of the passenger car tyres on the Dutch market. In 1996, BEM had 13 collectors who collected 21 450 tonnes of used car tyres. From this amount, 56 % was reused while 20% was directly reused in Africa, Spain, Brazil or Eastern Europe. Remaining 36% was retreaded in Germany and Eastern Europe. Only about 4% was used in physical applications and 9% recycled in the Netherlands. About 31% was incinerated with energy recovery in the cement kilns in Germany and Belgium. The data is summarised *Table 7.5*.

Table 7.5 Processing of car tyres collected within replacement collection system

Option	Percentage	Location
Product reuse		
• direct reuse	20	• Africa, Spain, Eastern Europe
• retreading	36	• Germany, Eastern Europe
Physical application	4	• the Netherlands
Material recovery	9	• the Netherlands
Energy recovery (cement kilns)	31	• Belgium, Germany
Collected tyres	21 450 tonnes	• the Netherlands

Source: BEM, 1998

Strengths and weaknesses of the Dutch collection systems: Both of the Dutch collection systems for used tyres are generally considered as well working and effective collection systems. In combination with adopted legislative instruments, these systems have already shown the following results in the national scale:

- No landfilling of used tyres;
- Approximately 50-60 % of product reuse (via direct reuse and retreading mainly abroad);
- Increasing number of certified collectors.

In spite of these positive results, the Ministry of Environment has identified the following weak points in the systems which should be improved:

- Low percentage of recycling compared to the nationally set target;
- Lack of reliable data on used tyres processed by different routes;
- Insufficient transparency in the economics of the systems;
- Large volumes of exported tyres.

7.2.3 Disposal Fee

In the Netherlands, the disposal fee is fully market driven set upon the commercial deals between the collectors and the processors. Because disposal fee represents important income for the tyre processing companies, it is obviously very difficult to obtain exact figures on disposal fee for individual processing options. Some of the Dutch collectors claim that the disposal fee is the same for material and energy recovery options which represents 83 ECU per tonne of passenger car tyres and 68 ECU per tonne of truck tyres.

Based on the interview with the ARN representative and taking into consideration a relatively high share of energy recovery options, it can be assumed that the disposal fee paid to cement kilns is lower than the disposal fee paid to grinding companies. Disposal fee for shredded tyres (TDF) gets usually lower than disposal charge for whole tyres. In some cases, it may have to be purchased as a fuel.

7.2.4 Configuration of processing options

Although there are several sources of data available on arising and processing of used tyres, the figures differ significantly. The country does not have a central monitoring system. The administrators of the two collection systems have figures only on passenger car tyres collected within their systems. The processing of used truck tyres is not publicly reported. Moreover, an extensive parallel export and import of used tyres, result of open border economy, contribute to the difficulties in monitoring of used tyres generated and processed in the country.

Based on several sources, the total amount of used tyres generated annually in the country is approximately 65 000 tonnes. According to VROM, up to 60% of this amount is reused (mainly abroad). About 32% is incinerated with energy recovery mainly in the cement kilns abroad and about 8 % of all used tyres is recycled (*Table 7.6*).

Table 7.6 Configuration of processing options in the Netherlands

Option	Percentage
Product reuse	60
Material recovery	8
Energy recovery	32
Total amount	65 000 tonnes

Source: VROM, 1998

Direct reuse: The collected tyres that still have a sufficient tread depth (above 1.6 mm) are sold for a direct reuse. The market can be found all over the world, mostly in Africa, South America and Eastern Europe.

Retreading: Retreading is very limited for passenger car tyres. It is of more significance for truck tyres. Approximately 150 000 truck tyres per year are retreaded in the Netherlands by several retreading companies. One the leading retreaders operating in the Netherlands is *Kargro* which has up to 60-70% share of the Dutch market. The company provides hot as well as cold retreading in the total annual amounts of 25 000 tyres and 40 000 respectively.

As concerns passenger car tyres, retreading is not common in the Netherlands; the collected casings are exported for retreading to other countries. Major market in Eastern Europe is covered by Poland, Slovak Republic, Slovenia, Bulgaria, Romania and Russia. Access to the market in the Czech Republic is fairly difficult because of a high competition with German exporters.

Grinding: There are several processing companies in the country which provide both mechanical and cryogenic grinding. The companies are spread all over the region. *Rumal* is one of the largest granulating companies in the Netherlands. It produces granulate using both mechanical and cryogenic technologies. In 1997, approximately 18 000 tonnes of truck tyres and about 10 000 tonnes of miscellaneous rubber waste were processed in the company. According to Rumal, approximately 35-40% of their production is used for sport surfaces. However, the market for application of granulate in sport surfaces is limited.

Reclaiming: In the Netherlands, a well established reclaim industry is represented by *Vredestein Recycling* located in Maastricht. Vredestein plays an important role on the European rubber market. Annually, it produces 15 000 tonnes of reclaim which is exported to most European countries. Vredestein is also a tyre producer. Although various market indicators such as falling prices of natural and synthetic rubber gave concern for production of reclaim in last years, an establishment of collaborative venture with Goodyear seems to be challenging. The co-operation with Goodyear started in 1996 in the framework of the Eureka subsidised Tamarrec project. The aim of the project is to develop car tyres with a maximum recycled rubber content in combination with an optimum performance.

Incineration in cement kiln: In the Netherlands, there is only one cement kiln—*ENSI*, located nearby Mastricht—incinerating shredded used tyres or other rubber compounds to supplement conventional fuels. Generally, a large amount of tyres is exported to northern part of Belgium where it is incinerated in cement kilns.

Pyrolysis: Currently, there is no pyrolytic facility for used tyres or tyre related rubber waste in the Netherlands. However, the Technical University in Eindhoven is involved in a research on the possibilities for pyrolysing rubber waste. Based on the interview with the researchers from the University, there has been several feasibility studies prepared for construction of pyrolytic units using annually up to 5 million tyres in the Netherlands.

Within the research on pyrolytic technologies, the most progressive technologies producing high quality end products were considered. One of such pyrolytic units, developed in the USA, met the qualitative requirements (carbon black and oil); however, the SO_2 emissions were significantly higher (285 mg/m^3) compared to Dutch national emission standards (200 mg/m^3). According to this study, the main problems for the pyrolysis are uncertainties in a continuous availability of tyres and relatively high process emissions of SO_2. On contrary, NO_x and hydrocarbons are of no significance.

7.2.5 Trade

Based on data from the *Central Office of Statistics of the Netherlands*, trade in used tyres and rubber waste from 1993 till 1996 for the Netherlands was determined (Figure 7.2).

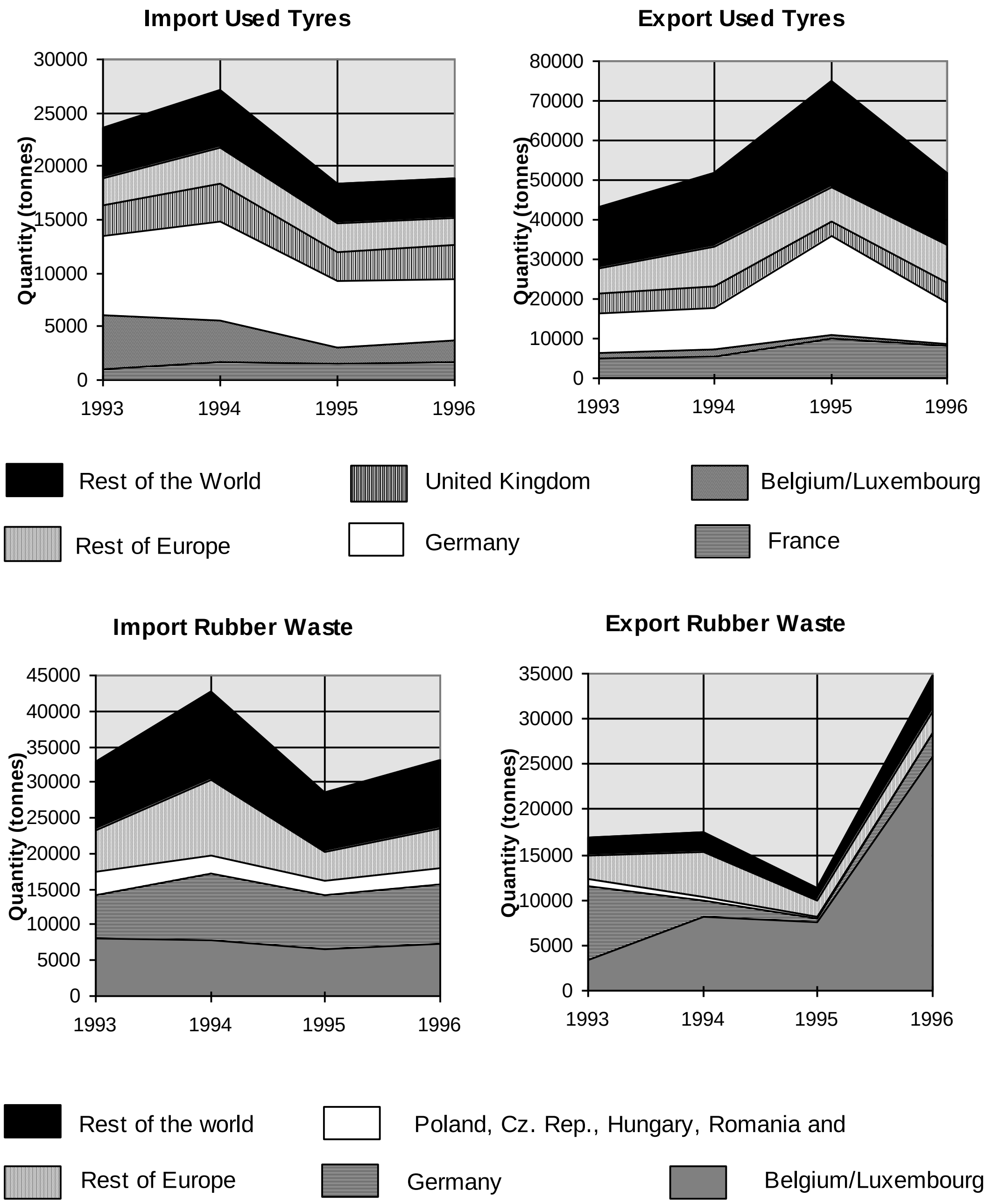


Figure 7.2 Export and import of used tyres and rubber waste in the Netherlands

The country is a net exporter of 30 000 tonnes of used tyres per year. The total volume of import and export in used tyres has declining tendency. Most of the used tyres are imported from Germany, United Kingdom and Belgium. Approximately 70% of the total volume of used tyres is exported to countries within Europe such as Germany, United Kingdom and other countries of Europe. In contrast, import and export of rubber waste are increasing. Approximately 50% of the import of rubber waste destines from Germany and Belgium. Nearly all export of rubber waste fates to Belgium/Luxembourg.

7.3 Conclusions from case studies

The previous sessions presented the actual patterns on the waste tyre management in the Czech Republic and in the Netherlands. The preferable attention was given to the following issues: policy framework, collection system, disposal fee, configuration of processing options and trade. This session provides a comparison of the Czech and Dutch scenarios; based on that, the main conclusions are drawn.

7.3.1 Policy

In the Czech Republic as well as in the Netherlands, the configuration of processing is influenced by the existing policy. The present policy framework shows similarities as well as differences in the two countries (Table 7.7).

Table 7.7 Comparison of the situation in the Czech Republic and the Netherlands

	Czech Republic	The Netherlands
Targets	none	set for the year 2000 60% product reuse 20% material recovery 20% energy recovery
Policy instruments	ban on landfill (1998) take back obligation (1998)	ban on landfill (1996) take back obligation (1995) voluntary agreements
Collection system	none	dismantling collection system (ARN) replacement collection system (BEM)
Disposal fee	15 - 30 ECU per tonne (0 ECU for cement kiln)	50 - 80 ECU per tonne

Compared to the Dutch policy which appears to be stabilised, the Czech policy related to the waste tyre management is currently in a transitional period. Although both countries have introduced identical legislative instruments such as ban on landfill and take back obligation based on producer liability, the level of their implementation differs significantly. In this respect, the Dutch experience might be considered as a useful example.

By introducing the ban on landfill for used tyres and take back obligation (expected also for tyres), the Czech policy has accepted a progressive step towards sustainability in accordance with the latest European trends. Unfortunately, a vague formulation of these two instruments within the present legislation does not seem to ensure a prompt improvement in the management of post consumed tyres. Moreover, a missing target can be recognised as insufficient motivation for the tyre industry to support the environmentally sound processing options.

7.3.2 Collection system

In the Netherlands, a well working and effective collection system contributes to safe disposal of waste tyres. In the Czech Republic, a collection system is completely missing which has a negative impact on tyre processing. An insufficient collection network causes irregular flow of used tyres from producers to processors within the country and affects negatively the efficiency in tyre processing which is frequently compensated by import of used tyres. Another consequence of missing collection system is a lack of transparency.

7.3.3 Disposal fee

The preferences in processing options are strongly dependent on disposal fees in both countries. In the Czech Republic, the average disposal fee varies between 15 and 30 ECU per a tonne of tyres for all the processing routes apart from incineration in the cement kilns where no disposal fee is charged at the present time. In the Netherlands, the disposal fee is approximately 50 to 80 ECU per a tonne of tyres for all the processing options. Most likely, the fee is higher for material recovery than energy recovery options.

7.3.4 Configuration of processing options

The Czech Republic and the Netherlands generate similar amounts of used tyres per year. The configuration of processing options appears to be comparable though the Netherlands process most of the arising abroad (see *Table 7.8*).

Both countries have large retreading capacities; however, promotion of the image of retreaded tyres is still needed. Energy recovery, mostly incineration in cement kilns, is more common than material recovery. Grinding and reclaiming face difficulties in terms of low market possibilities for obtained end products. At present, there are no operating pyrolytic facilities in these countries. Landfilling which was the most common option for disposing used tyres in the Czech Republic until 1997 and in the Netherlands until 1995, has been already prohibited in both countries.

Table 7.8: Comparison of processing patterns

Option	Percentage	
	The Czech Republic	The Netherlands
Product reuse	32	60
Material recovery	8	8
Energy recovery	25	32
Landfilling	35	0
Total amount	60 000 tonnes	65 000 tonnes

Source: Estimates 1998; VROM, 1998

7.3.5 Trade

According to our study, the neighbouring countries of the Czech Republic and the Netherlands are the major partners in trade on tyres and tyre related rubber waste. It seems that trade will occur as long as it is economically feasible for processing companies. Disposal fee and distance are the most significant aspects in trade. Differences in disposal fee can be considered as a driving force for trade, whereas distance plays a role is a limiting factor.

8. Analysis and evaluation of processing options

In the previous chapters, a lot has been said about the policy, economic and environmental context of tyre waste management. The question remains, taking all these criteria into account, which processing options are eventually preferable in tyre waste management. For instance, are the economic benefits of using tyres as a fuel in a cement kiln larger than the associated environmental externalities? Or, from a social point of view, should pyrolysis be supported so that it leaves its experimental scale? These and other questions are addressed in this chapter.

The main aim is to compare and identify which is the best possible option for processing used tyres from economic and environmental point of view. The assessment covers the following processing options: hot retreading, cold retreading, mechanical grinding, cryogenic grinding, reclaiming, pyrolysis and incineration in cement kilns. Considering that environmental performance of the cement kilns may differ depending on the characteristics of tyre input, we included two alternative cement kilns.

The first part of the chapter sets out the methodology and gives a short description of the economic and environmental assumptions considered in this assessment. The second part presents the results of the cost benefit analysis and the economic valuation of the environmental externalities. Based on these results, it determines the net social benefits for each used tyres processing option. The last part, presents the conclusions of the assessment.

8.1 Overall methodology

In order to analyse the processing options on a quantitative and multidisciplinary basis, several methodologies have been combined. These include Life Cycle Assessment (LCA), Cost Benefit Analysis (CBA), Economic Valuation (EVA) and the extended Cost Benefit Analysis (extended CBA). As can be seen in Figure 8.1, these methodologies can only be applied in a specific chronological order. In this section, each applied method will be explained briefly.

The first step comprises of defining the main goal of the analysis and setting the system boundaries. The main goal is to determine the financial, external (environmental), and social costs and benefits of the various processing options in the tyre waste management. The scope of the assessment is limited to the case of truck tyres.

The assessment has been based on data collected from tyre processing plants in the Netherlands and the Czech Republic. Most of the companies preferred to remain anonymous and thus are not mentioned as a data source within the analysis. Some of the data were compiled from available literature.

Financial costs and benefits are defined as those costs and benefits which are directly accounted for by the actors involved. *External costs* are those costs which an individual or firm undertaking some activity imposes on another party through this activity without having to pay for them. For example, the incineration of used tyres may cause hazardous emissions which in turn may cause damage to human health. Finally, the *social costs and benefits* are defined as the sum of financial and external costs and benefits. In this context, social costs or benefits can more or less be regarded as the measure stick for sustainable development. The lower the social costs (or the higher the social benefits), the more sustainable an option is.

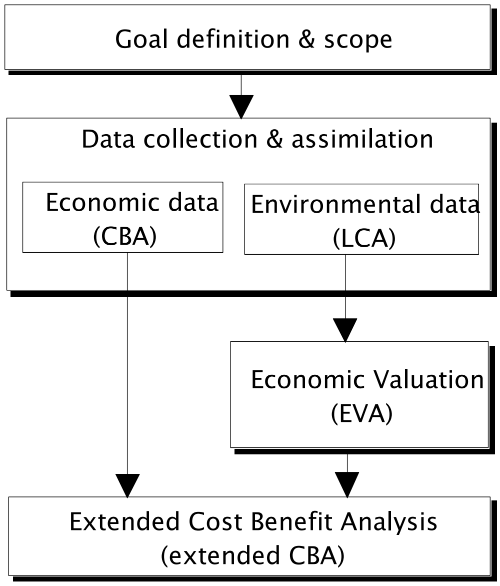


Figure 8.1 Overall approach of the analysis

The financial (private) benefits are determined within the CBA as a difference between private costs and revenues. Costs include investment costs (technology, buildings, etc.), operation costs (energy, water, materials), maintenance costs (replacements, labour costs and other inputs). Transport costs are not considered separately since these are assumed to be included in operational costs. Revenues include prices of outputs which can be sold. These data are usually well reported, since they determine the financial feasibility of a company.

The determination of the environmental costs and benefits is less straightforward. First, the LCA was applied to evaluate the environmental impacts of processing a certain quantity of used tyres. In each option, the life cycle starts at the point at which tyres become waste and are disposed of. The LCA includes the direct emissions of the actual process, emissions of energy generation necessary for the process and emissions of transport. In cases when further useful by products are generated, the avoided burden approach is applied.

In the next step, the outcome of the LCA has to be weighted in such a way that it can be combined with the financial variables. There are various approaches for this so called valuation stage of the LCA. These include, among others, methods in which the weight of a parameter is determined by the environmental policy objectives which have been expressed ("distance to target" methods) or by the costs of controlling that particular emission. Other techniques use the scores attributed to the different environmental impacts by experts, interested parties or public opinion as weighting factors.

In this project, the intermediate step between the LCA and the extended CBA is based on economic valuation (EVA) of the externalities. In the EVA, the importance of environmental quality (like that of any other scarce good) is determined by individual preferences, expressed in monetary units. This last approach is preferred by us for several reasons. First, it provides the possibility to combine the derived external values with internal financial costs thereby enabling a full CBA. Second, economic valuation is considered to be the least arbitrary weighing procedure of environmental impacts.

Table 8.1 summarises the range of external values applied in the EVA. Since transport related emissions have a rather specific impact, other values have been used for this process. It is important to emphasise that mortality related to transport is has not been considered within this study. It is beyond the scope of this report to explain the full background of external values. It should be noted, however, that each value has a wide range of underlying assumptions and uncertainties. Therefore, a warning of caution in using the values is applicable. An elaborate background for these values can be found in Beukering et al. (1998).

Table 8.1 Applied external values

Impact category		value	unit
Global warming	CO_2	5.1	ECU/tonne
Human health	NO_x nitrate	718	ECU/tonne
	NO_x ozone	18 000	ECU/tonne
	SO_2 direct	629	ECU/tonne
	SO_2 indirect	6 953	ECU/tonne
	particulates	18 000	ECU/tonne
	VOC	602	ECU/tonne
	heavy metal	15 000	ECU/tonne
	Zn	15	ECU/tonne
	HC	602	ECU/tonne
	solid waste	2.12	ECU/tonne
Natural resources	SO_2 damage to forest	1.25	ECU/tonne
	SO_2 damage to agriculture	8.27	ECU/tonne
	SO_2 damage to lakes	1.45	ECU/tonne
Buildings	dust and particulates	300	ECU/tonne
	SO_2	260	ECU/tonne
Disamenity	solid waste	5	ECU/tonne

Source: Beukering et al., 1998

By multiplying the emission levels with the external values per unit, the total external costs and benefits of a processing option can be determined. In the extended CBA, these external costs and benefits are combined with the financial costs and benefits in order to determine the social value. Obviously, the preferred option is the option with the highest net social benefits or the lowest social costs.

8.2 Economic assumptions

In the process of determining the financial costs and benefits, several assumptions have been made. These assumptions relate to investment costs, maintenance and operational costs, transport, energy, labour costs, input prices and output revenues. The assumptions are explained in the following section.

Investment costs: For all of the processes, data on investment costs has been obtained from interviewed companies. In calculations of investment costs per one tonne of processed tyres, we assumed that the life expectancy for each company is 15 years. Based on the present production capacity, we have calculated the total amount of tyres processed within a company during its lifetime. By dividing the total investment costs by the total amount of tyres processed in 15 years, we have obtained the investment costs per one tonne of tyres.

The investment costs among selected processes vary between 19 ECU per tonne of pyrolysed tyres up to 44 ECU per tonne of ground tyres. In the case of the cement kiln, the investment costs included in further analysis were only costs necessary for modifications to the cement production facility which are required when tyres are incinerated. Such modifications include installation of storage equipment, conveying belt, metering system and additional pollution abatement technology.

Maintenance and operation costs: Direct data on maintenance and operation costs were available only for some processes. In several cases when the exact maintenance costs were missing, such as in the case of retreading and granulation, the maintenance costs used in further analysis have been considered to be 10% of the total investment costs. Rather high maintenance costs for grinding are due to expected high failure rate of grinding technologies.

Transportation: Although transportation cost is an important economic variable directly influencing gross profit of companies, costs associated solely with transport have been excluded from the CBA in this study. However, it can be argued that indirectly the transport costs are included in the price of input and output materials.

Energy: Most of the technologies for processing used tyres are energy intensive, requiring fairly large amount of energy input. For the cement kilns, the energetic input has not been included because in this process scrap tyres are used as the energy source. In general, the input of electricity varies from 180 kWh per tonne of pyrolysed tyres up to 580 kWh reclaimed tyres.

Costs associated with the use of energy have been calculated from the total energetic input for individual processes and price per unit of energy. Price of electricity included in this report equals 0.1 ECU per kWh which is the 1997 market price of electricity for industrial purposes in the Netherlands.

In addition to consumption of electric power, retreading and pyrolysis use gas inputs. In calculations of the total expenses associated with gas consumption required for retreading, price of 0.137 ECU per 1 m^3 has been considered in the CBA. Costs associated with the use of gas for pyrolysis have not been included considering the fact that the process uses only gas produced by pyrolysis. These costs appear in lower revenues.

Labour: Companies involved in processing used tyres are in majority cases small and medium size businesses employing between 15 - 75 employees. In the study, annual labour input cost of 22 800 ECU per worker has been considered. The cost is slightly above the average annual income of a skilled worker in the Netherlands.

Inputs: Prices of input materials covered in this study include the average market prices in 1997 as they have been obtained from the interviewed stakeholders, predominantly processing companies. All input prices considered in this study are given in Appendix XII.

It is important to note that prices of post consumed tyres depend on their quality which to a certain extent predefines the final processing, especially in the case of tyres suitable for retreading. Average price of a part worn truck tyre suitable for cold retreading, often offered on the market as casing, is 44 ECU per a piece (812 ECU per tonne of tyres). Part worn tyres processed in hot retreading are cheaper about 36 ECU (660 ECU per tonne).

Furthermore, worn out tyres as input materials for grinding, pyrolysis and incineration in cement kiln bring benefit which equals to disposal fee of approximately 52.8 ECU per tonne of tyres. Collectors of used tyres pay this disposal fee to processing companies for their disposal. In our calculations, the disposal fee has been included as output revenue.

Outputs: Although the prices of final products and by products fluctuate, we considered in our analysis average prices provided for year 1997. For tyres retreaded by using cold retreading, price 137 ECU per piece (2 537 ECU per tonne) is considered. The price of hot retreaded tyres is about 124 ECU per piece (2 300 ECU per tonne).

Price of rubber granulate varies mainly depending on the size of granules. Finely ground granulate (0.1 mm - 0.5 mm) is almost twice as expensive as rubber crumb. In our analysis, we included average price 286 ECU per tonne of mechanically ground granulate. The considered average price of granulate obtained through cryogenic grinding was 330 ECU per tonne of granulate. The average price of cryogenic granulate is higher compared to mechanically ground granulate because cryogenic grinding produces larger amount of fine granules which ultimately increases value of granulate.

The last important rubber based output is reclaim. Quality of reclaim is considered to be significantly higher than that of granulate, especially if it is used as a filler in new tyres. One tonne of reclaim costs about 506 ECU which is almost twice as much as price of granulate.

Steel, textile, oil and carbon black are useful non rubber based products obtained during processing of used tyres. Revenues from their production have been calculated based on the output volume from relevant processes and prices which are listed in Appendix XII.

8.3 Environmental assumptions

The environmental impacts, expressed in tonnes of pollutants per a tonne of tyres, are divided into four emission categories based on their origin: direct emissions from the actual process, emissions associated with energy use, transport emissions and avoided burdens.

Direct emissions: For each option, the major air pollutants such as NO_x, SO_2, CO, heavy metals, hydrocarbons, particulates and solid waste have been taken into account. Water pollutants have not been considered since water effluents play a minor role in all the processing options. Due to a lack of unit damage estimates for noise, this effect is omitted.

Energy emissions: In order to express emissions associated with energy use, average emissions from energy generation in Europe were used (Vroonhof et al., 1996). Emissions associated with production of minor inputs such as tread, unvulcanised rubber, additives and extraction of raw materials have not been considered.

Transport emissions: Emissions from transport have been expressed based on available emission data for 16 tonne truck loaded with 13.7 tonnes. It consumes 0.0243 litres of diesel per one kilometre with 1 tonne of load (Lim et al., 1994). Tyres were assumed to be twice as voluminous as other products; therefore, double amount of diesel and consequently twice as much emissions have been accounted. The distance of 100 kilometres has been considered in order to assess the environmental impact of transport on the national level. For evaluating the international transport, the distance of 1000 kilometres has been calculated.

Avoided burdens: Avoided burdens have been expressed as saved emissions associated with the energy required for direct production of individual end products (steel, rubber, oil, etc.). If the quality of end product was expected to be lower compared to a new product, the related amount of saved energy has been reduced. Detailed description of assumptions considered for individual processing options is presented in Appendix XIII.

Weight of a tyre: In the LCA performed within this study, the average weight of a truck tyre was considered to be 60 kg. According to the literature, approximately 10 to 15% of tyre weight is lost during its life span; in this study, the losses of 10% were assumed. The weight of an input worn out tyre was considered to be 54 kg.

8.4 Cost benefit analysis

The total financial profit (benefit) has been calculated by subtracting the total financial costs from revenues. The results of the CBA are presented in Figure 8.2, Figure 8.3 and Figure 8.4. Figure 8.2 depicts the allocation of financial costs and benefits for eight processing options under study. Relative composition of financial costs of these options is shown in Figure 8.3. Finally, Figure 8.4 illustrates the relative composition of financial revenues. A more elaborated overview of the exact costs and benefits of the researched options is summarised in Appendix XIV.

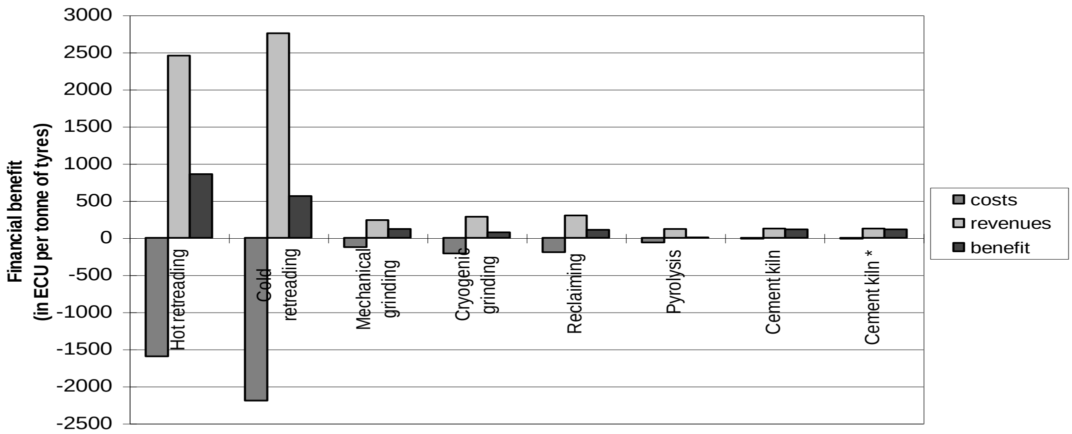


Figure 8.2 Allocation of financial costs and benefits

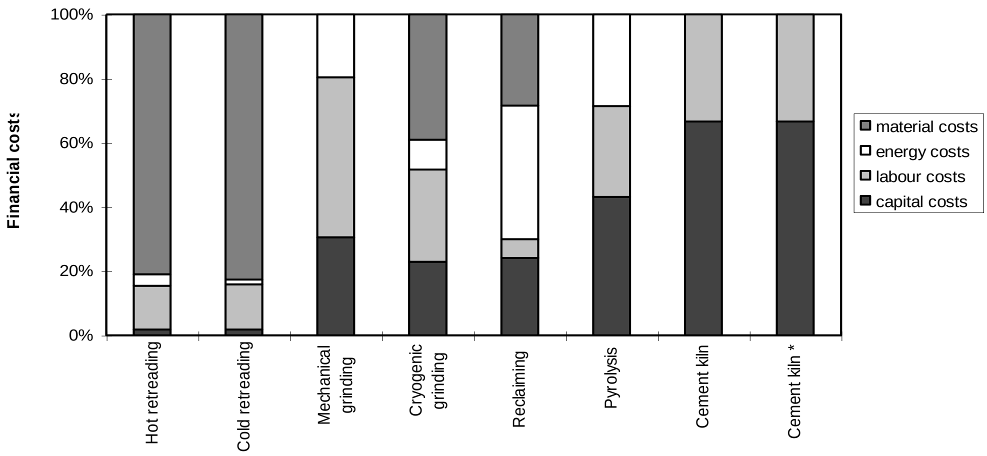


Figure 8.3 Relative composition of financial costs

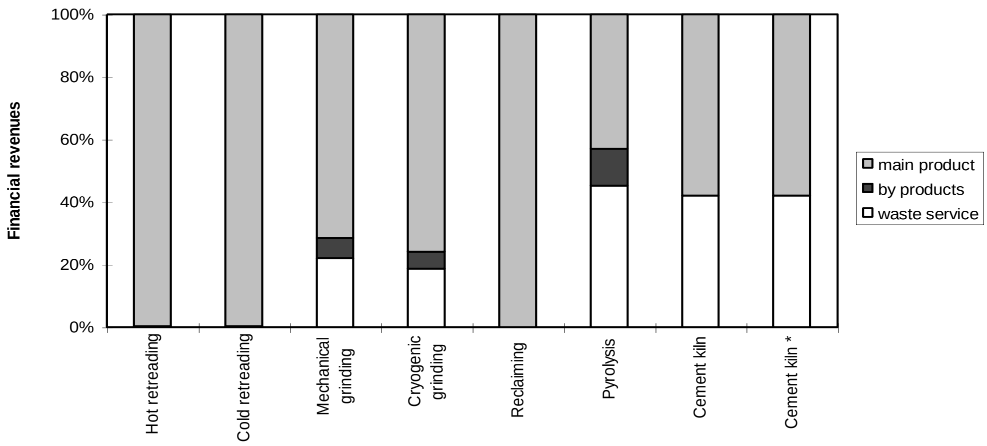


Figure 8.4 Relative composition of financial revenues

Retreading is clearly the most desirable option from economic point of view. In terms of profitability, hot retreading is preferred to cold retreading. Cold retreading requires about 25% higher capital costs, as well as, higher input costs. Compared to other processing options retreading is the least labour intensive after reclaiming. On the other hand, about 80% of the total economic costs are material costs. These include costs for casing, tread and unvulcanised rubber. Looking at the relative composition of private revenues, almost 100% of the total revenue come from sales of the main products (i.e. retreaded tyres).

Allocation of financial costs for individual processes is quite diverse. Looking at the financial benefits of all processing options, mechanical grinding, incineration in cement kilns and reclaiming are ranking almost on the same place while their total gross profit varies between 117.6-114.9 ECU per tonne of tyres.

Mechanical grinding appears to be the most financially profitable processing option for worn out tyres which cannot be retreaded. Almost 40% of the total economic costs comprises of labour costs and the remaining 60% includes capital costs and energy costs. The composition of economic costs for cryogenic grinding differs. The process depends on the price of coolant. Almost 40% of the costs are associated with high price of nitrogen. It should be noted that both mechanical and cryogenic grinding have an average of 20% net revenue from waste services and about 10% from by products (i.e. steel). The remaining revenues are from sales of the main product (i.e. granulate).

Financial benefit of incineration in cement kilns makes this option financially profitable. The financial performance of both cement kilns is identical. The only alternation between the cement kiln and the cement kiln* is due to their different environmental performance. It should be noted that almost 65% of the total economic costs are associated with capital costs (i.e. investment costs required for modification of the process). Remaining 35% are labour costs. The private revenue comes from energy recovered from the burning of used tyres (55%) and disposal fee.

The relative composition of financial costs of reclaiming is rather diverse. It seems to be the most energy and the least labour intensive process. About 45% of the total economic costs are associated with the use of energy. Labour represents relatively small share of less than 10%. Capital and material costs, each of them having comparable share, have about 50% of the total economic costs. In view of net private revenue, 100% of the economic benefit arises from the main product (i.e. reclaim).

From economic point of view, pyrolysis appears to be the least profitable among the assessed options. The actual gross profit of the process is 10.9 ECU per tonne of processed tyres. Almost 50% of the total economic revenue is from waste service, which is relatively high compared to the other processing options. The advantage of pyrolysis is that there are almost no energy costs involved. In contrast, it requires very high investment costs.

It should be pointed out that in our analysis, we have calculated the revenues for end products of pyrolysis considering them to be utilised as fuels. Such assumption is rather realistic, corresponding with the position of pyro products on the European market. Considering the potential of these products to be used as raw materials in the future (if their quality improves as a result of improved technology which will eventually stabilise their position on the market), financial profitability of pyrolysis may change substantially.

8.5 Life cycle analysis

The total external (environmental) costs are derived from emissions associated with process, transport and avoided burden. *Process emissions* cover direct emissions from the actual process and emissions related to the energy use. *Transport emissions* represent the impact of long distance transport. *Avoided burden* is a sum of all considered avoided burdens.

For the LCA, the main results are presented in Figure 8.5, Figure 8.6 and Figure 8.7. The allocation of external costs is presented in Figure 8.5. Figure 8.6 shows the allocation of emissions by origin. Background information on the data used in the LCA can be found in Appendices XV and XVI. The differences in total external costs between long and short distance transport are demonstrated in Figure 8.7. Since these differences are not very significant, only the scenario of long distance transport was used in further analysis.

From Figure 8.5 it can be seen that all the studied processing options have external benefits thus ultimately overall positive impact on the environment. The process associated environmental costs and avoided burdens are of significance for all the processing options, whereas transport is of lesser importance. Retreading is the most environmentally promising option since it shows the highest external benefits.

Pyrolysis and reclaiming followed by grinding have comparable overall environmental performance. It should be noted that the direct emissions of pyrolysis are rather significant. However, the external costs associated with the process are levelled out by avoided burdens which may even increase when the quality of obtained products improves.

Reclaiming, mechanical and cryogenic grinding have relatively low external costs related to processes as well as avoided burdens. The overall environmental performance of two grinding options is nearly the same. Compared to mechanical grinding, cryogenic grinding shows slightly higher direct emissions in terms of particulates, lower emissions related to consumed energy and higher avoided burdens of energy associated with quality of rubber granulate.

Incineration in cement kilns appears to have the lowest external benefits; however, there is a significant difference between considered cement kilns. The first *cement kiln* burns whole tyres without any pre processing. The other alternative, *cement kiln**, uses buffed and unbelted tyres. The buffed out rubber crumb and steel coming from tyre belt are recycled which results in higher avoided burden.

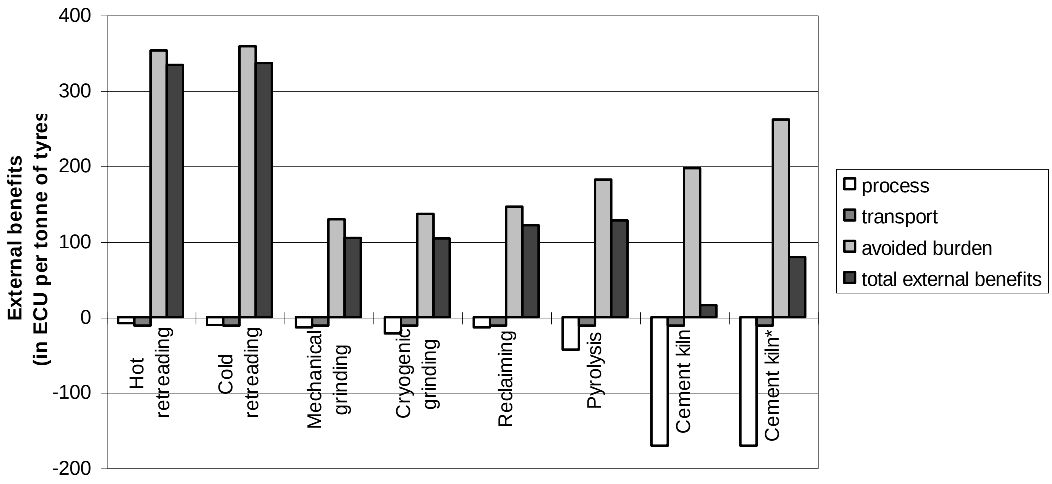


Figure 8.5 Allocation of total external costs and benefits

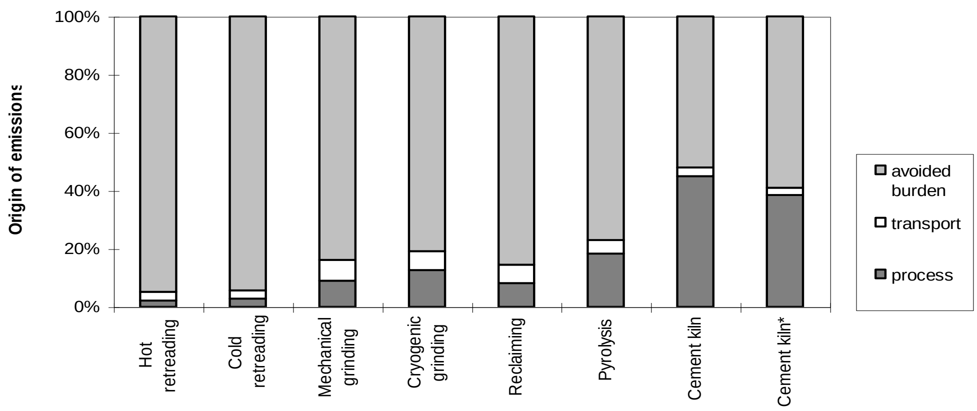


Figure 8.6 Allocation of emissions by origin

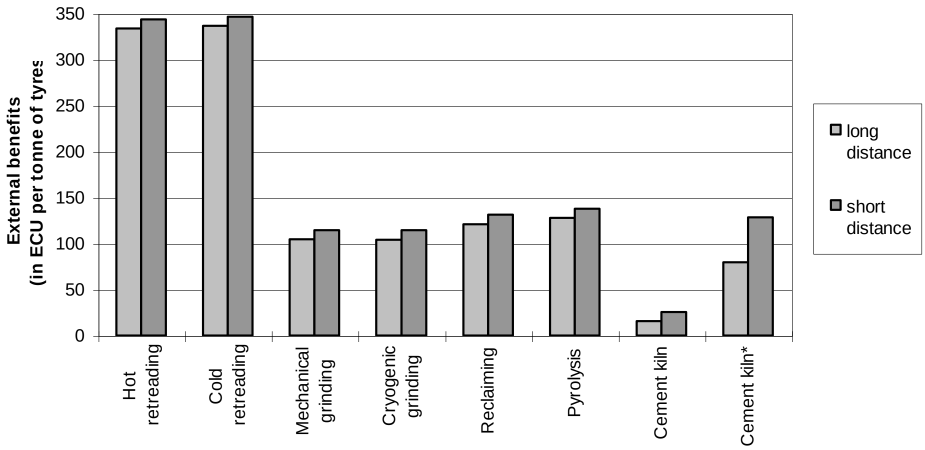


Figure 8.7 External costs of short and long distance transport

The following figures show contribution of individual processing options to separate environmental impact categories: global warming, human health, damage to natural resources, damage to buildings and disamenity.

Global warming is related to emissions of CO_2 and other greenhouse gases which contribute to absorption of radiation and consequently to the increase in global temperature. According to Figure 8.8, all studied processing options have positive impacts on global warming; that means they represent avoided burdens in terms of CO_2 emissions. Retreading appears to have the best environmental performance in this impact category followed by incineration in cement kilns and pyrolysis. Reclaiming and grinding seem to have comparable contribution to global warming.

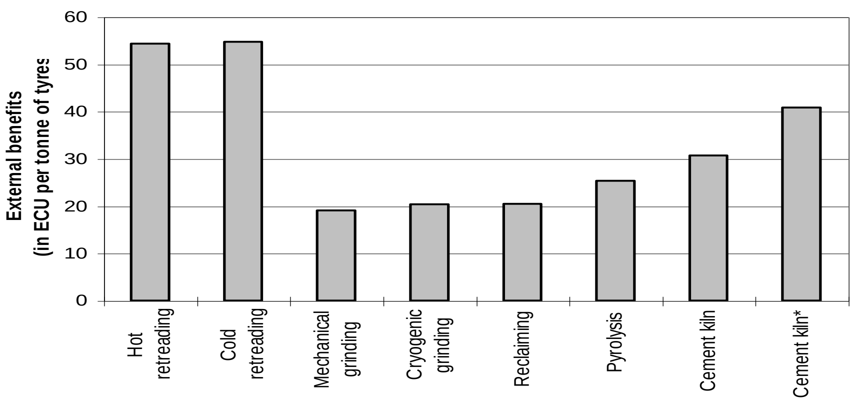


Figure 8.8 Impact on global warming

The category *human health* includes contribution of NO_x, SO_2, CO, heavy metals, and other air emissions to potential occurrence of health problems. Figure 8.9 shows that incineration in the cement kilns has the lowest environmental performance in terms of human health. This is caused by relatively high direct process emissions of CO and NO_x. In the case of cement kiln*, the process emissions are levelled out by higher avoided burdens resulting in overall positive contribution to human health. Reclaiming and pyrolysis followed by grinding have approximately the same contribution to this category. The most positive impacts on human health can be attributed to retreading.

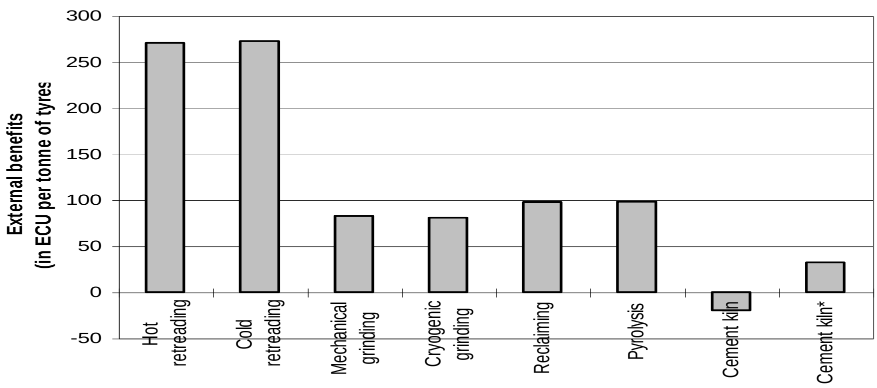


Figure 8.9 Impact on human health

The impact category *natural resources* includes potential damage to forests and lakes by acid deposition of SO_2, and damage to agriculture by deposition of SO_2 and NO_x. Figure 8.10 illustrates that all the processing options contribute to deterioration of natural resources as a consequence of acidification. The acid deposition is due to high energy consumption and related pollutants. When interpreting the results presented in Figure 8.10, it should be noted that it shows external costs whereas all the other figures of impact categories depict external benefits.

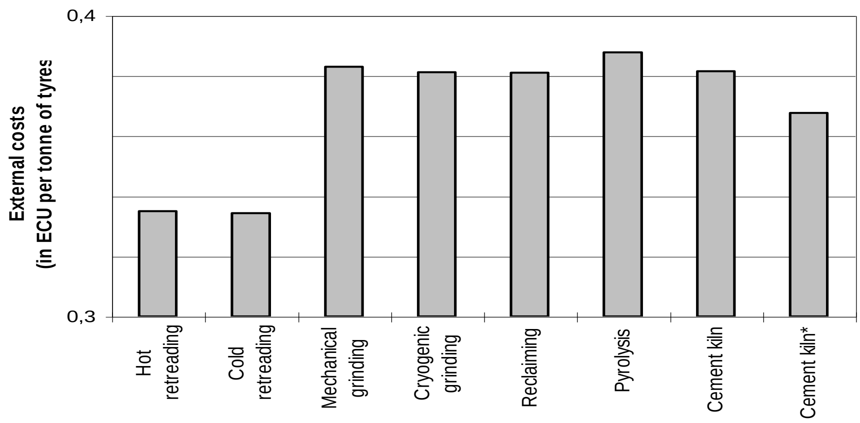


Figure 8.10 Impact on natural resources

The impact category *damage to buildings* includes the potential impact of SO_2 and dust to corrosion of buildings. As it appears from Figure 8.11, all studied processing alternatives do not cause additional damage to buildings. It is notable that in this category, reclaiming and incineration in cement kilns perform better compared to grinding and pyrolysis. This implies to significant energy saving, consequently, avoided SO_2 emissions.

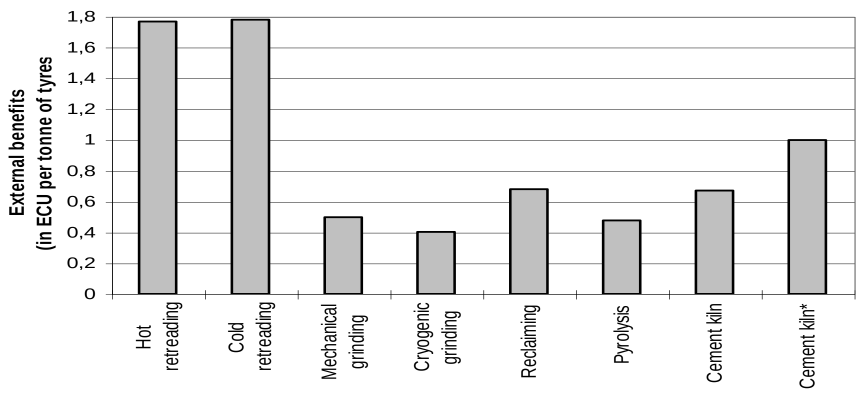


Figure 8.11 Impact on buildings

Within this study, the impact category *disamenity* includes all environmental impacts caused by the solid waste disposal. The highest environmental benefits in this category have retreading, followed by incineration in cement kilns and pyrolysis. Grinding and reclaiming seem to have the lowest external benefits as far as concerns disamenity (Figure 8.12).

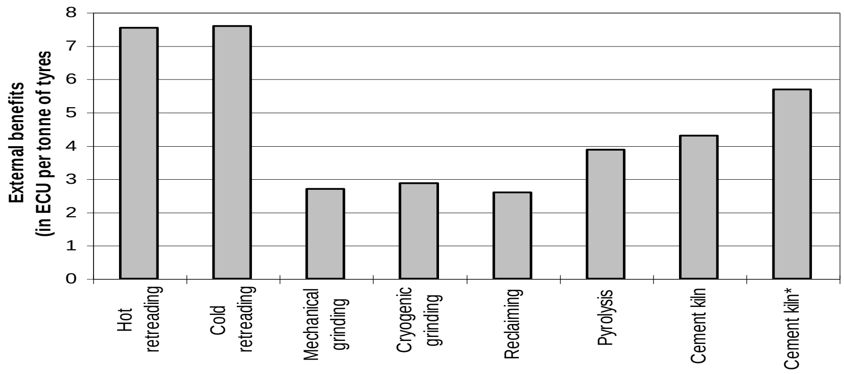


Figure 8.12 Impact on disamenity

8.6 Extended cost benefit analysis

The main aim of the extended CBA has been to identify total social benefits of tyre processing options which comprise of total financial and external benefits. Based on the analysis of the highest social benefits in descending order, the most and the least promising scrap tyre processing scenarios have been identified.

Figure 8.13 shows the social benefits of individual processing options. As it appears from this graph, the most desirable processing option with the highest social benefit is retreading, including both available technologies hot and cold retreading. The gap between retreading and the other options is quite significant.

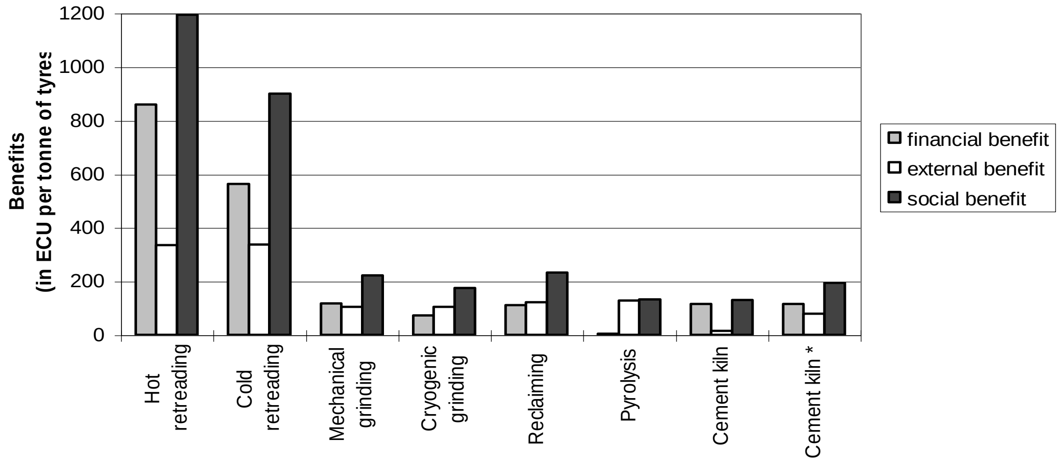


Figure 8.13 Allocation of total social benefit

Reclaiming ranks as the second option with total social benefits 232 ECU per tonne of tyres. It should be noted that the environmental benefit of this process is higher than its financial profit.

Although mechanical and cryogenic grinding bring almost identical environmental benefits, their financial benefits differ. As a result, social benefit of mechanical grinding is higher compared to cryogenic. Considering the fact that financial revenue of cryogenic grinding is in linear correlation to the price of nitrogen, stabilisation of nitrogen price on the market can have a positive impact on the overall financial benefit and make both grindings comparable.

Incineration in cement kilns ranks after reclaiming and grinding. From social point of view, incineration of buffed and unbelted tyres (cement kiln*) is more desirable. Compared to other processing alternatives, the external benefits from burning tyres in cement kilns are lower. Nevertheless, there is a significant difference between two cement kilns included in our analysis. The cement kiln* appears to have five times higher external benefits than the other cement kiln which is a consequence of increased avoided burdens. Financial benefits that constitute the majority of the social benefits equal in both cases. Because of substantial avoided burdens and comparable process emissions, cement kilns using tyres as supplementary fuel have lower external costs compared to cement kilns which use conventional fuels such as coal and oil.

Pyrolysis seems to be the least socially beneficial processing route. In the case of pyrolysis, the financial benefit is relatively low and external benefit comprises a dominant part of the overall social benefit. From environmental point of view, pyrolysis ranks as a rather promising option, on the same level as reclaiming. Although our analysis has shown marginal financial benefit, improved pyrolytic technology resulting in higher quality of end products can have positive impact on the financial revenues.

9. Conclusions and discussions

The increased number of vehicles during the last decades have led to a dramatic increase in the number of waste tyres to be disposed of. In the total waste stream, used tyres represent only a limited volume but their overall characteristics may cause environmental problems especially if not properly managed.

This chapter highlights the main findings and conclusions of the study. First, the focus is on the context of waste tyre management. Next, conclusions are drawn with regard to the feasibility of various processing options. Finally, the conclusions are presented on the case study countries: the Czech Republic and the Netherlands.

9.1 The context of tyre waste management

9.1.1 Tyre

Tyres are a valuable source of materials and energy. Disposal without material and energy recovery is a waste of valuable natural resources and should therefore be avoided. In addition, disposal in landfills represent potential risks for the environment and public health. Despite these facts are commonly accepted—proven by the ban on landfill of tyres in several European countries—landfilling is still performed on a large scale.

Looking at the life cycle of a tyre, it was found that extended life span of a tyre is an important factor which can be addressed. Stabilisation of a tyre primary production in most industrialised countries proves that the increase in the number of vehicles has been levelled out by the prolonged tyre life due to improved tyre quality. Additionally, driver's behaviour has an essential influence on tyre wear. Extended tyre life span is not only a marketing advantage, but it also prevents use of materials and contributes to rubber waste minimisation. Involvement of tyre manufacturers in the whole life cycle of a tyre appears to be an evolving trend in the tyre production with positive impacts on processing of post consumed tyres.

9.1.2 Trade

To get an indication of the significance of international trade in used tyres, a comparison was made with the international trade in new pneumatic tyres. Although the importance in value terms is limited, the trade analysis proved that, in terms of physical flows, used pneumatic tyres account for approximately 14% of the total tyre related trade.

If the trade in *used tyres* is considered in more details, Germany, the Netherlands, France, UK and Poland are identified as the main actors in the trade on used tyres. Notable, the UK is a net importer, whereas Germany, the Netherlands and France are net exporters. Another interesting trade flow of used tyres is directed from the EU towards countries of Eastern Europe. Flows of used tyres are driven by demands for direct reuse and retreading of second hand tyres.

The total trade volume of *tyre related rubber waste* is comparable with the total trade volumes of used tyres in Europe. Sweden is by far the largest net importer of tyre related rubber waste. Although it is impossible to identify processing alternatives based on the waste commodity traded, it appears that rubber waste, possibly granulate, shipped to Sweden is destined for energy recovery. The Netherlands is the largest exporter of rubber waste, however, looking at the overall trade balance, the import and export are almost identical.

Market prices of traded commodities and transportation costs appear to be the driving forces or limiting factors of trade in Europe. Differences in market prices justify the volumes shipped in Europe. Import of part worn tyres to UK and Eastern Europe for reuse or shipment of rubber waste, as an inexpensive fuel, to Sweden are only a few remarkable examples. In this respect, availability of processing options also plays an important role, though, it is difficult to prove this hypothesis. In terms of economic feasibility, transportation costs are limiting factors of trade in used tyres and tyre related rubber waste. Local trade in used tyres between UK and France or in rubber waste between the Netherlands, Germany and Belgium are among the best examples.

Lack of transparency is a main constraint leading to incompleteness of data on trade flows of used tyre and tyre related rubber waste. The available data is incomplete and not very accurate. There are great differences between reporting on arrivals by importing countries and reporting on the same trade flow by the exporting countries. In this respect an improved database quality and monitoring on national, European or global levels are essential. This requires the introduction of obligatory notification to national governments on used tyre generation, processing and trade flows.

9.1.3 International and EU policy

The developments in policies on international and EU levels have direct impacts on the national waste management strategies and frameworks in Europe including both Member States and accession countries. Therefore, it is important to highlight the main features and trends evolving on the supranational level.

In accordance with the international and EU regulations, shipment of waste tyres is governed as trade in non hazardous waste while tyres are listed on the green list (OECD, EU Regulation on shipments of waste) and B list (Basel Convention). Waste on the green and B list is commonly traded without further restrictions unless otherwise specified.

Waste hierarchy, which underlies the European waste policy, is an important concept applied in the EU waste management strategy. It proposes a list of waste management options which are defined in descending order of priorities including the prevention, recovery and final disposal. The principles of hierarchy apply to all waste streams, including used tyres.

Based on the recommendations prepared by the Priority Waste Stream Group, several features in tyre management have been discussed in EU, whereas the degree of implementation on the EU level is still limited. Ban on landfill of used tyres and tyre waste, included in Proposal for Directive on the Landfill of Waste is among the most important recommendations which are expected to be implemented. If implemented the ban on landfill will promote environmentally more sound waste management practices which will have positive impacts on the environment.

Stetting targets for used tyres and tyre waste, specified for all individual management routes including prevention and collection, is another trend which evolved on the EU level. Although the implementation of targets set for tyres on the EU level is rather uncertain, these play important role in setting national targets all around Europe.

In addition, voluntary agreements has been recognised within the EU as a primary measure which should be considered within national policies when managing the waste tyre streams. Voluntary approach in combination with the producer responsibility is recommended also by the reviewed 1996 Community Strategy for Waste Management which calls for their adoption in national waste management strategies.

9.1.4 Waste tyre management pattern in Europe

Based on the above provided description of used tyre management practices in selected European countries, it appears that many countries took progressive measures to deal with the used tyre arisings. Although the practices in individual countries differ, the following trends seem to be evolving overall in Europe.

A number of European countries have undertaken legislative initiatives towards sustainability in rubber and tyre industry. The most common policy instruments applied in the waste tyre management include the ban on landfill, the producer liability often specified as take back obligation on both used tyres and end of life vehicles. Several countries have set up their targets within the national policies. Additionally, voluntary agreements involving governments and industries have already proved to be effective in several European countries, such the Netherlands and Germany.

Collection is one of the first actions to be taken in order to prevent waste to be disposed off. Recovery and recycling cannot be performed without a proper collection network aimed to optimise sorting and distribution of collected materials. Although in many countries the collection system has not been developed and well structured yet, the current trends show that more advanced European countries, such as Denmark, Germany, the Netherlands, Norway and Sweden has taken essential measures to collect used tyres more efficiently.

The collection system is financed either by *product charges* included in the price of new tyres or by *recycling fee* charged when a tyre is collected. Product charges are set either legislatively (Denmark, Hungary and partly the Netherlands) or by industry (Norway, Slovakia and Sweden). Recycling fee is in all cases driven by market (Germany, the United Kingdom, partly the Netherlands). The establishment of collection systems is frequently supported by nationally set targets.

The prohibition of landfill adopted in several countries, increasing cost of landfilling and the appreciation of tyre rubber as a clean fuel seem to push waste tyre routes from undesirable dumping and dispersion to energy recovery. If this trend continues, the termination of the disposal on land can be foreseen in a few years which will have a positive impact on scrap tyre management in Europe.

Recovery of waste is at the core of any sustainable waste management policy. Material and energy recovery, is an important target set by the EU and countries with advanced environmental policies. At the national level, different countries have adopted legislation aiming to implement the reuse of pneumatic tyres in different ways. It can be anticipated that the industrial consolidation of new cost effective technologies will contribute to shift recovery partially from energy to material recovery. One important option appears to be retreading of used tyres.

9.2 Processing options

During our study, available options for post-consumed tyres and tyre related rubber waste in Europe have been investigated. Based on the situation in European countries, we have identified and assessed processing alternatives which seem to have a promising market potential as well as a positive environmental performance. These options include retreading, grinding, reclaiming, pyrolysis and incineration in cement kilns. In order to identify the best possible waste tyre management route, both the financial (CBA) and the environmental feasibility (LCA and EVA of the externalities) have been determined. Combining the results of these assessments lead to an extended CBA.

Based on the results from extended CBA, retreading seems to be the preferred processing option (Figure 9.1). This route has the highest financial and external benefits, consequently, the highest social benefit. A significant gap exists between the benefits of retreading and the other options. In fact, the social benefit is more than 5 times as high as the next favoured option. The notable gap remains a challenge for material and energy recovery options to increase the overall economic and environmental performance. In the following paragraphs, each option is discussed individually.

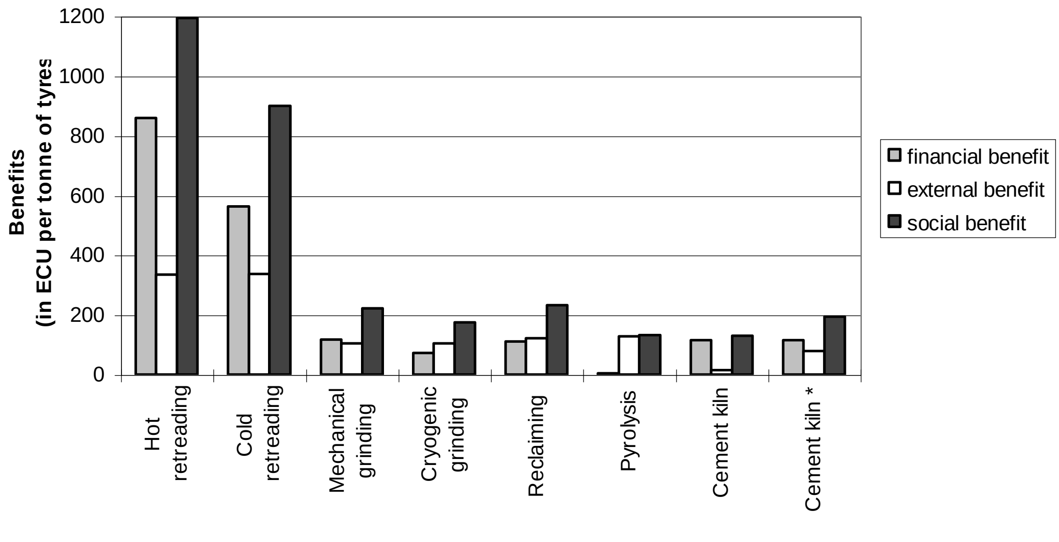


Figure 9.1 Social benefits of processing options for used tyres

9.2.1 Retreading

Considering the fundamental roles of reduction and minimisation of waste volume in waste management, it is important to pay attention to retreading which is the only method of using tyres for the original purpose. Retreading prolongs the average life of a tyre. It saves 80% of raw materials and energy necessary for production of a new tyre and reduces the quantity of waste to be disposed. From this reason, it is important to encourage production of retreadable tyres and their actual retreading.

It is important to promote retreading by all possible means including prolonging the life span by producing retreadable tyres and improving their image, thus create markets for re-treaded tyres. Possible measures for achieving this are to:

- Implement quality standards for tyre manufacturers requiring retredeability of tyres;
- Implement quality standards for retreading industry (for instance ISO 9 000);
- Introduce incentive based instruments on retreaded tyre (such as lower VAT), to promote its use;
- Promote public procurement policy (use of retreads on governmental vehicles);
- Support research on safety of retreads;
- Provide information to the public on the quality and existence of retreaded tyres.

Considering its economic and environmental benefits, retreading should be seen as the first step in tyre post consumption stage. If a tyre does not meet the technical requirements for further retreading, the tyre life cycle may be closed with material or energy recovery alternatives.

9.2.2 Material recovery

Grinding and reclaiming appear to be among the promising and profitable ways to recover material from rubber waste. Despite a positive environmental performance and a substantial market potential of grinding and reclaiming, the application of these two processes is still limited. Lack of a market outlet for end products are the main economic barriers for a wide spread use of these waste management options. In this respect, studies on the market opportunities for recycled rubber and optimisation of recycling technologies are essential.

Pyrolysis is a processing alternative which seems to have very good prospects from an environmental point of view. At present, the technology is not economically feasible due to high investment costs, doubtful quality of pyrolytic products and virtually non existent demand for these products. As a consequence, attention should be paid to improvement of the technology, increasing quality of pyrolytic product and development of markets for these products.

From environmental point of view, material recovery saves valuable resources and reduces amount of tyres to be disposed of. From economic and technological point of view, these alternatives still need to be grown and encouraged. It is essential that markets for recycled materials are developed. This can be achieved by:

- Set up targets for tyre industry to use recycled rubber in new products;
- Introduce tax subsidies (lower VAT) on products with set recycled content;
- Develop quality standards for granulate;
- Propagate recycled rubber in governmentally financed projects (e.g.rubberised asphalt);
- Recognise granulate as secondary raw materials within the trade HS system, which will give recycled rubber a positive economic value;
- Support fundamental research and development of new technologies and market opportunities for rubber recycling, including pilot projects for pyrolysis and other innovative processing technologies.

9.2.3 Energy recovery

Using tyres as an alternative fuel is an economically feasible option. Benefits derived from combustion of tyres with energy recovery lead to savings of conventional fuels. If the emission standards of incineration facilities are met, the environmental impact can be minimised. Compared to some conventional fuels such as coal and oil, these impacts can even be reduced, because mining activities are avoided. Additionally, the sulphur content in the tyres is generally lower than in conventional fuels which can lead to decreased SO_2 emissions.

The most significant potential markets for the energy recovery of scrap tyres include production of steam, production of electricity, incineration in cement kilns, lime kilns, paper mill boilers and application in other industries. Among these applications, incineration in cement kilns appears to be the most widely applied recovery route for worn out tyres. The environmental performance can be even increased when cement kiln uses pre-processed tyre while the buffed out rubber crumb and steel coming from the tyre belt are recycled.

Incineration with energy recovery is an economically feasible method for processing scrap tyres. It may be encouraged as a viable option, until the markets for products of material recovery will be improved. Implementation of emission standards for operations using tyres as alternative fuel, their monitoring and research of new relevant pollution abatement technologies should be promoted in order to avoid potential environmental impacts. Possible solutions are to:

- Introduce emission standards for facilities using tyres as an alternative fuel;
- Develop efficient monitoring system on implementation of standards;
- Support research on pollution abatement technologies in order to prevent emissions and losses of the incineration processes;
- Support research on energy recovery from scrap tyres in other energy intensive industries (pulp and paper mills, steam boilers, tyre to energy dedicated plants);
- Encourage rubber processing industries, especially retreading companies, to recover energy from waste within their production.

9.3 Conclusions for the Czech Republic and the Netherlands

In order to provide more detailed overview of the current situation in management of post consumed tyres and tyre related rubber waste, we selected two case study countries with different waste tyre management practices: the Czech Republic and the Netherlands. Waste tyre management in the Czech Republic is under transition driven by the process of approximation to the EU standards and strategies. The Netherlands represents the Member States with well established waste management practices considered to be a leader in this field.

9.3.1 Policy

In the Czech Republic as well as in the Netherlands, the configuration of processing is influenced by the existing policy. Compared to the Dutch policy which appears to be stabilised, the Czech policy related to the waste tyre management is currently in a transitional period. Although both countries have introduced identical legislative instruments such as the ban on landfill and producer liability, levels of their implementation differ significantly. In this respect, the Dutch experience might be considered as a useful example.

By introducing the ban on landfill of used tyres and take back obligation based on principles of producer liability, the Czech policy has accepted a progressive step towards sustainability in accordance with the latest European trends. Unfortunately, a vague formulation of these two instruments within the present national legislation does not seem to ensure a prompt improvement in the management of post consumed tyres. Moreover, a missing target can be recognised as insufficient motivation for the tyre industry to support the environmentally sound processing options.

9.3.2 Collection system

In the Netherlands, a well working and efficient collection system contributes to safe disposal of waste tyres. In the Czech Republic, a collection system is completely missing which has a negative impact on tyre processing. An insufficient collection network causes irregular flow of used tyres from producers to processors within the country and affects negatively the efficiency in tyre processing. The irregular tyre supply is frequently compensated by import of used tyres. Another consequence of missing collection system is a lack of transparency.

9.3.3 Configuration of processing options

The Czech Republic and the Netherlands generate similar amounts of used tyres per year. The configuration of processing options appears to be comparable though the Netherlands process most of the arising abroad. Both countries have large retreading capacities; however, promotion of the image of retreaded tyres is still needed. Energy recovery, mostly incineration in cement kilns, is more common than material recovery. Grinding and reclaiming face difficulties in terms of low market possibilities for obtained end products. At present, there are no operating pyrolytic facilities in these countries. Landfilling which was the most common option for disposing used tyres in the Czech Republic until 1997 and in the Netherlands until 1995, has been already prohibited in both countries.

9.3.4 Disposal fee and trade

The disposal fee has a major impact on the preferences in tyre processing options in both countries. In the Netherlands, the disposal fee is significantly higher than in the Czech Republic which has positive impact on economic feasibility and ultimately social profitability of tyre management.

In fact, differences in disposal fees within Europe can be considered a main driving force for international trade. According to our study, the neighbouring countries of the Czech Republic and the Netherlands are the major partners in trade on tyres and tyre related rubber waste. It seems that trade will occur as long as it is economically feasible for processing companies.

10. Recommendations to the Czech Republic

In the previous chapter the most remarkable conclusions were summarised. From both economic and environmental points of view, it is very important to prolong the life time of a tyre. Extending tyre life span is much more than a marketing advantage; it prevents use of materials and contributes to rubber waste minimisation. Implementing the following recommendations into the Czech waste tyre management strategy, may lead to reducing of the environmental impacts associated with management of used tyres in the country.

10.1 Implement ban on landfill

Landfilling of post consumed tyres should be abandoned in the Czech Republic. *For this purpose, the ban on landfill for used tyres recently introduced in the new waste legislation should be fully implemented in short term*. Considering vague legislative formulation of the ban, its effectiveness remains doubtful. Possible measures to completely eliminate landfill of tyres are to:

- Include more explicit formulation of the ban into the national waste legislation;
- Develop and implement monitoring of the landfill prohibition;
- Apply monofilling as an alternative option for the transitional period till landfill is completely abandoned; ensure that monofilled stocks are managed by environmentally sound practices;
- Establish a statistic system which includes data on volumes of used tyres and processing routes; require processors to follow the obligatory notification included in the legislation; consider obligatory verification of data by an independent third party;
- Increase public awareness and disseminate information on available material and energy recovery routes for used tyres.

10.2 Develop a collection system

A well established collection system is an essential part of environmentally and economically sound waste tyre management practices. It can reduce the cost of overall tyre processing by eliminating unnecessary flows within the region and ensure that collected tyres are transferred to appropriate facilities for future processing.

Since an effective collection system for used tyres is completely missing in the Czech Republic, primary focus should be placed on its development. Possible ways to involve the main stakeholders and encourage them to establish a collection system are to:

- Set targets on tyre recovery applicable for tyre industry; possibly include targets into the national legislation;
- Adopt a clear formulation of the producer liability into the national legislation;
- Introduce the producer liability for end of life vehicles;
- Initiate voluntary agreements between industry and authorities;
- Consider short term legislative inclusion of economic instruments (product charges, recycling fee) if the voluntary approach does not prove to be feasible;
- Encourage certification of used tyre collectors;

- Increase public awareness and disseminate information on available material and recovery routes for used tyres.

10.3 Promote retreading

Retreading should be seen as the first step in management of post consumed tyres. It saves 80% of raw materials and energy necessary for production of tyres and reduces the quantity of waste to be disposed. *Retreading, therefore, should be promoted by all possible means including prolonging the life cycle by producing retreadable tyres and improving their image, thus create markets for retreaded tyres*. Possible measures to achieve that are to:

- Implement quality standards for tyre manufacturers to produce retreadable casings;
- Implement quality standards for retreading industry (for instance ISO 9000);
- Use economic instruments on retreaded tyre (such as lower VAT);
- Promote public procurement policy (use of retreads on governmental vehicles);
- Provide information to the public on the quality and existence of retreaded tyres.

10.4 Develop markets for other processing options

Unavoidably, a tyre will end up in the waste stage. The final recovery routes will decrease the environmental impacts considerably compared to landfilling. From environmental point of view, material recovery is a preferred to energy recovery. However, lack of markets for the recovered material are the main cause of their lower economic feasibility. *Markets for recycled materials should be created and energy recovery should be promoted, especially in short term until material recovery is feasible*. Available measures are to:

- Introduce tax subsidies (lower VAT) on products with set recycled content;
- Set up targets for tyre industry to use recycled rubber in new products;
- Propagate recycled rubber in governmentally financed projects (e.g.rubberised asphalt);
- Support fundamental research and development of new technologies and market opportunities for rubber recycling, including pilot projects for pyrolysis and other innovative processing technologies.

- Introduce emission standards for facilities using tyres as an alternative fuel;
- Develop efficient monitoring system on implementation of standards;
- Stimulate the use of pre-processed tyres which allows partial recovery of materials (steel, buffed rubber);
- Encourage rubber processing industries, especially retreading companies, to recover energy from waste within their production.
- Support research on pollution abatement technologies in order to prevent emissions and losses of the incineration processes;
- Support research on energy recovery from scrap tyres in other energy intensive industries (pulp and paper mills, steam boilers, tyre to energy dedicated plants);

References

Afvalverbrandingsinstallatie Amsterdam-Noord (1990). Management Consultancy and Research for Environmental Management, Inzameling en Verwerking van Autobanden in de Regio Amsterdam. CREM.

Ausplund, J. (1996). Scrap Rubber-An Unpredictable Waste or a Useful Raw Material. Rubber in the Environmental Age-Progress in Recycling, pp. 1-7.

Autoexpert (1998). Kam s nimi?, Auto Expert, No. 3, March 1998, pp. 30-32.

Auto Recycling Nederland BV (1998). Environmental Report 1997.

Baarle, B. van., Hage, H.(1992). Gebruikte Autobanden- een Inventarisatie, Kunstof en Rubber. Kunststoffen en Rubberinstituut TNO, Delft.

Bandag (1988). Truck Tyre Retreading. A guide for Fleet Owners, Managers, and Specifiers. Bandag Incorporate.

Barlaz, M.A., Eleazer, W.E., Whittle, D. J. (1993). Potential to Use Waste Tires as Supplemental Fuel in Pulp and Paper Mill Boilers, Cement Kilns and in Road Pavement. Waste Management & Research nr. 11, pp. 463-480.

Barum (1997). Prohlášení k životnímu prostøedí.

Beck, M. (1993). Ultra Modern Banden Verwerkingsbedrijf in Lommer van Start-Jakobus Rubber Recycling week gedwongen uit naar Belgie. Recycling, No. 27, pp. 92-93.

Benson, C. (1995). Using Shredded Scrap Tires in Civil and Environmental Construction. Resource Recycling, pp. 71-74.

Beukering, P. J. H van, Curlee, T. R. (1997). Recycling of Materials: Local or Global? In: P. Vellinga , J. Gupta and F. Berkhout (eds): Substantial Sustainability. Kluwer Academic Press. Forthcoming.

BIR (1997). Bureau of International Recycling, Annual Report.

BIR (1997). Bureau of International Recycling, Impact of the Basel Convention and Trade Ban on the Supply of Secondary Raw Materials.

Blumenthal, M. (1997). Scrap Tire Market Analysis. Biocycle, pp.70-72.

Boršè, M. (1995). Skúsenosti z prevádzky technologickej linky na recykláciu starých pneumatik. Životní prostøedí, Vol. 29, No. 6, pp. 306-309.

Bressi, G. (1997). Recycling of Used Tyres. Institute for the Environment, Milan, Italy, pp. 131-139.

Brisson, I. E. (1997). Externalities in Solid Waste Management: Values, Instruments and Control.

Burlett, R. (1996). Rubber Recycling in the European Community, Vredestein.

Cecich, V. et al, (1996). Use of Shredded Tires as Lightweight Backfill Material for Retaining Structures. Waste management & Research, No. 14, pp. 443-451.

Cembureau (1997). Alternative Fuels in Cement manufacture, Technical and Environmental Review.

Centrum voor Energiesbesparing en Schone Technologie (1996). Financiele Waardering van de Milieu-Effecten van Afvalverbrandingsinstallaties in Nederland.

Chang, Y. M. (1996). On Pyrolysis of Waste Tire; Degradation Rate and Product Yield. Resources, Conservation and Recycling, pp. 125-139.

Club de Bruxelles (1997). The New European Strategy for Waste Management. Club de Bruxelles Conference.

Commission of the European Communities (1989). Community Strategy for Waste Management (SEC/89/934 final).

Commission of the European Communities (1991). Used Tyres, Information Document.

Commission of the European Communities (1994). Proposal from the Working Group to the European Commission for a Recommendation on the Prevention, Recovery and Disposal of used Pneumatic Tyres *(COM/XI/454/93-EN).*

Commission of the European Communities (1995). Report from the Commission to the Council and the European Parliament on Waste Management Policy.

Commission of the European Communities (1996). Communication from the Commission to the Council and the European Parliament on Environmental Agreements.

Commission of the European Communities (1996). Progress Report from the Commission on the Implementation of the European Community Programme of Policy and Action in Relation to the Environment and Sustainable Development: Towards Sustainability *(COM/95/624 final).*

Commission of the European Communities (1996). Communication form the Commission on the Review of the Community Strategy for Waste Management *(COM/96/399 final).*

Commission of the European Communities (1997). Proposal for a Council Directive on the Landfill of Waste *(COM/97/105 final).*

Commission of the European Communities (1997). Proposal for Directive on environmentally friendly handling of End of Life Vehicles. *(COM/97/358 final).*

Council of the European Communities (1975). Council Directive on Waste *(75/442/EEC).*

Council of the European Communities (1990). Resolution of the Council concerning waste management *(90/C/ 122/02).*

Council of the European Communities (1991). Council Directive amending Directive 75/442/EEC on Waste *(91/156/EEC)*.

Council of the European Communities (1993). Resolution on a Community Programme of Policy and Action in Relation to the Environment and Sustainable Development, Fifth Action Plan (5AP), *(93/C138/01).*

Council of the European Communities (1991). Council Directive amending the Directive 75/442/EEC on Waste *(91/156/EEC).*

Davis, J.(1996). How to Solve a Problem. Tire Review, pp. 38-39.

Decree of the Minister of Environment and Regional Policy (1995). Decree on the Enforcement of Act LVI on Env. Protection Product Charges and the Environmental Protection Product Charges of Certain Products. Hungary *(10/1995 IX.28).*

Doig, A.; Clift, R. (1995). Life Cycle Assessment of Waste Tyre Disposal. Centre for Environmental Strategy, University of Surrey.

Duffy, D. P.(1995). Using Tire Chips as a Leachate Drainage Layer. Waste Age, pp. 113.

Dufton, P.(1995). Scrap Tyres, Disposal and Recycling Options. In: A Report from RAPRA's Industry Analysis and Publishing Group.

Dufton, P. (1996). Scrap Tire Disposal into the 21st Century. WME, pp. 16-22.

Economic Commission for Europe (1997). Uniform Provision Concerning the Approval of Pneumatic Tyres for Agricultural Vehicles and their Trailers.

Economic Commission for Europe (1997). Uniform Provision Concerning the Approval of Pneumatic Tyres for Commercial Vehicles and their Trailers.

Economic Commission for Europe, (1997). Uniform Provisions concerning the Approval for the Production of Retreaded Pneumatic Tyres for Commercial Vehicles and their Trailers.

EPA (1995). Environmental Protection Agency, Items Designated in the Comprehensive Procurement Guideline-Supporting Analyses, USA.

EPA (1996). Environmental Protection Agency, Scrap Tire Shipping Papers. Columbus, Ohio, USA.

EPA (1997). Environmental Protection Agency, Final CPG II/RMAN II Background Document, USA.

EEA (1995). European Environment Agency, Europe's Environment, The Dobøíš Assessment. EEA, Copenhagen.

ETRA (1994). European Tyre Recycling Association, Proceedings of the First International Conference on Tyre Recycling. Brussels.

ETRA (1996). European Tyre Recycling Association, The Third European Conference on Tyre Recycling.

ETRA (1996). European Tyre Recycling Association, Proceedings of the Third International Conference on Tyre Recycling. 30-31 May Brussels.

Ferrer, G. (1997). The Economics of Tire Remanufacturing. Resources, Conservation and Recycling, No.19, pp. 221-255.

Government Decree (1995). Decree on Certain Measures Necessary for the Enforcement of Act LVI of 1995 on Environmental Protection Product Charges and the Environmental Protection Product Charges of Certain Products, Hungary (113/1995IX.27).

Hoffmann, U. (1997). Opportunities and Constraints for Internalisation of Environmental Costs and Benefits: The Case of Natural and Synthetic Rubber. Presentation at the International Rubber Forum, 12-13 June 1997, Liverpool

Hond, F., den. (1996). De voorwaarden voor en de vorm van samenwerking bij integraal ketenbeheer - de ontwikkeling van recyclingswstrategieen door autofabrikanten Milieu tijdschrift voor Milieukunde, pp. 103-111.

IPTS (1996). Institute for Prospective Technological Studies . The Recycling industry in the European Union: Impediments and Prospects. Sevilla.

IRSG (1998). International Rubber Study Group, Rubber Statistical Bulletin. Vol. 52, No.4, England.

Koèíková, P. (1997). 5. akèní program, IPPC a nová strategie ES pro nakládání s odpady, Sborník pøednášek Menzinárodní konference a výstava Odpady Praha 97, str. 11-14.

Kok, V. (1994). Autoband Wordt Hulpmotor voor Cementindustrie- Oplossingen voor de Bandenberg Gezocht. Magazine Recycling Benelux Jrg. 28.

Kox, H. L. M. (1997). Internalisation of Environmental Externalities in Primary Rubber Economy. Notes for Introduction at IRSG Meeting, Liverpool 1997, ESI/VU, Amsterdam.

Kreizlová, D. (1997). Stav a trendy zpracovaní ojetých pneumatik v Èeské republike, SPUR akciová spoleènost, January 1997.

Lemieux, P. M. (1994). Pilot-Scale Evaluation of the Potential for Emissions of Hazardous Air Pollutants from Combustion of Tire-Derived Fuel. Environmental Protection Agency (EPA)

Lim, M.; Lindeijer E.(1994). Milieubeoordeling van Beglazingssystemen.

Lopes, H., Cabrita, I.(1995). Waste Tyres in the Cement industry. Department of Combustion an End Use Energy Technologies, Paris.

Makarov, V. M.; Drozdowsky, V. F. (1991). Reprocessing of Tyres and Rubber Waste (Recycling from the Rubber Products Industry). Ellis Horwood Limited, Chichester.

Malloy, M. G. (1997). Rolling Tires into Rubber. Waste Age, pp. 85-89.

Matoušek, P. (1996). Likvidují nebezpeèný odpad: I v Èechách musí jednou nastat konec divokých skládek. Profit, No. 48.

Ministry of Environment of Norway (1995). Regulations relating to the disposal, collection and recycling of discarded tyres.

Nekvasil (1996). Pryž, Príruèka pro nakládání s odpady, Kutná Hora, str. 14.1-14.11.

Nicoletti G. M., Notarnicola B. (1998). Inventario del Ciclo di Vita del Pneumatico. Ambiente, Risorse, Salute, XVII 62, Padova, Italia.

Odpady (1996). Recyklace pneumatik zkapalòováním, Odpady, No. 5, pp. 23.

Odpady (1998). Pneumatiky a pryž, Odpady, No. 1, pp. 8-13.

Overdijk, R. (1990). Berg Autobanden Wordt Straks Kleiner. Nieuwe Secundaire Gronstof Door Uniek procede. Ingenieurskrant -Jrg. 2, pp. 15.

Parasiewicz, W. (1996). Ecological Aspects of Rubber Industry Development. International Rubber Digest.

Pokludová, E. (1993). Pryžové odpady a jejich využití. Odpad, No. 7-8, pp. 46-49.

RAPRA (1996). Tyres as a Source of Energy. RAPRA Report 1996.

Reiter, B.; Stroh, R. (1995). Use of Waste in the Cement Industry. Federal Environmental Agency-Austria.

Reschner, K. (1997). A general Overview of Commonly Used Scrap Tire Processing and Rubber Recycling Method. http://www.snafu.de/kurtr/.

Riggle, D. (1994). Finding Markets for Scrap Tires - Utilization Options - Legislation, Cooperative Marketing and Support for Existing Technologies Have the Potential to Turn Tires into a Valued Community. Biocycle, Vol. 35, No. 3 , pp. 41-44, 53-55.

Rikken, B. (1994). Een Bedrijf Zonder Bedrijfsafval. Afval en Reststoffen, jrg. 2.

Scrap Tire Management Council (1997). Scrap Tire Use/Disposal Study 1996/1997. Serumgard&Blumenthal Edition, Washington DC.

Smith, F. G. et al (1995). Testing and Evaluating Commercial Applications of New Surface - Technology Utilizing Waste Tires. Resources, Conservation and Recycling, No.15, pp. 133-144.

Statistics Netherlands (1995). Material Flows and Input-Output Analysis, Methodological Description and Empirical Results.

Stoyer, L. (1994). Scrap Tire Solution by Year 2000? MTD, pp. 40-42.

Swyka, M. A. (1996). Alternative Construction Materials in Waste Containment Applications. Waste Age, pp. 111-122.

UNCTAD (1996). A Statistical Review of International Trade in Tyre and Tyre-Related Rubber Waste for the Period 1990-1994. United Nations Conference on Trade and Development, Papers on Commodity Resources, Trade and Environment, No.1 Geneva.

UNEP, Secretariat Basel Convention (SBC) (1989). Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal, Geneva.

UNEP (1997). Technical Working Group of the Basel Convention on the Transboundary Movement of Hazardous Wastes. Disposal Technical Guideline on the Identification and Management of Used Tyres.

Vanhoutte, P. (1994). Recycling van Autobanden International in het Slop- Goede en Goedkope technologie Laat op zich Wachten. Recycling, No. 28, pp. 84-85.

Vredestein Rubber Recycling BV (1996). Rubber reuse is best all round. European Rubber Journal.

VROM (1996). Milieu-Analyse Verwekingsmethoden van Kunstofonderdelen van Afgedankte Auto's. Eindrapport.

Watson, P. J. (1996). Recent Developments in Central and Eastern European Countries. International Rubber Study Group (IRSG).

Watson, P. J.(1996). Commercial Vehicle Tyres-Developments and Elastomer Usage. International Rubber Study Group (IRSG).

Warmer Bulletin (1998). Eco-taxes and Waste Management, Journal of the World Resource Foundation, July 1998, No. 61.

Weaver, P. M.; Landis Gabel H. (1996). Optimizing Environmental Product Life Cycles: A Case Study of the European Pulp and Paper Sector. Environmental and Resource Economics, pp. 1-27.

Weerd, M., Wierenga, K. (1990). Informatiedocumenten Afvalstoffen, Waste Tires. RIVM, Bilthoven.

Weerd, M., Wierenga, K. Autobanden. RIVM, Bilthoven.

Werkgeversorganisatie voor de Banden- en Wielenbranche (1993). Branchedocument Bandenrecycling.

World Tyre Industry (1997). Tyre Recycling and Disposal. World Tyre Industry, The Economist Intelligence Unlimited, pp. 22-38.

Appendix I. List of Interviews

Asamer-Gruppe operation Úhy u Velvar (March 1998). Landfill, Retigová, Úhy u Velvar, the Czech Republic.

Association of Tyre Processors (June 1998). Janèa T., Prague, the Czech Republic.

Assogomma (July 1998). Consorzio per il Riutilizzo e lo Smaltimento dei Pneumatici Usati, association for tyres, Mantegazza P, Milano, Italy.

Barum Continental (March 1998). Tyre manufacturer, Gargulák J., Otrokovice, the Czech Republic.

BEM (July 1998). Band & Milieu, Association for Tyres and Environment, Adrian J. W., Leidschendam, the Netherlands.

BIPAVER (August 1998). Bureau International Permanent des Association de Vendeurs et Rechapeurs de Pneumatiques, ten Bruggencate B., Brussels, Belgium.

BIR (March 1998). Bureau of International Recycling, Veijs F., Brussels, Belgium.

BLIC (March 1998). Bureau de Liaison des Industries du Caoutchouc, Cinaralp F., Brussels, Belgium.

Cement Kiln Mokrá (March 1998). Okleštìk K., Mokrá, the Czech Republic.

Centre for Environmental Science at Leiden University (February 1998). Huppes G., Leiden, the Netherlands.

CICPEN (June 1998). Czech Industrial Coalition on Packaging and the Environment, Kozel, Prague, the Czech Republic.

Commission of European Communities DG XI—Environment (March 1998). Grohs S., Brussels, Belgium.

Commission of European Communities, DG III—Industry (March 1998). Stella, Brussels, Belgium.

Commission of European Communities, DG XI—Environment (March 1998), Wieringa, Brussels, Belgium.

Czech Ecological Institute (March 1998). Havránková V., Prague, the Czech Republic.

Eko-Rubber (March 1998). Rubber processing company-reclaim production, Horsáková M., Otrokovice, the Czech Republic.

ETRA (April 1998). European Tyre and Recycling Association, Shulman V., Brussels, Belgium.

Faculty of Economics at Free University (March 1998). Kox H. L. M., Amsterdam, the Netherlands.

Faculty of Economics at Free University (February 1998). Professor Smit H.P., Amsterdam, the Netherlands.

FEBELCEM (July 1998). Fedaration de l'industrie cimentiere Belge, Bouchat R., Brussels, Belgium.

General Directorate of Customs of the Czech Republic (March 1998). Dvoøáèek V., Prague, the Czech Republic.

KAC (March,1998). Tyre granulation plant, Janèa T., Uherský Brod, the Czech Republic.

Kargro (March 1998). Tyre retreading company, van der Heijden K., Montfoort, the Netherlands.

Kaučuk (March 1998). Rubber research institute, Èermák J., Kralupy nad Vltavou, the Czech Republic.

Ministry of Environment of the Czech Republic (March, June 1998). Mikulová V., Prague, the Czech Republic.

Ministry of Environment and Energy (July 1998). Danish Environmental Protection Agency, Grau P., Copenhagen, Denmark.

Ministry of Environment of the Slovak Republic (July 1998). Fichnová L., Bratislava, the Slovak Republic.

Norwegian Pollution Control Authority (July 1998). Granerud B., Oslo, Norway.

Obnova (March 1998). Tyre retreading company, Urban E., Brno, the CzechRepublic.

Rumal (March 1998). Tyre granulation plant, Melein A., Weerth, the Netherlands.

SDAB (August 1998). Svensk Dackatervinning AB, Aman L., Sweden.

Škoda (March 1998). Research institute on machinery, Forman R., Plzeò, the Czech Republic.

Svaz prùmyslu druhotných surovin (March 1998). National branch of Bureau of International Recycling (BIR), Horák M., Prague, the Czech Republic.

Swiss Agency for the Environment, Forests and Landscape (August 1998). Frey B, Industrial Waste Section, Basel, Switzerland.

Tasy (March, June 1998). Tyre collector and importer, Ševèík Z., Mokrá, the Czech Rep.

UNCTAD (March, July 1998). United Nations Conference on Trade and Development, Hoffmann U., Geneva, Switzerland.

Ústav nerostné suroviny odpady (March 1998). Raw materials and wastes research company, Tøebichovský, Kutná Hora, the Czech Republic.

Voegel publishing (June 1998). Martinec J., journalist, Prague, the Czech Republic.

VOZ (July 1998). Zement Industrie, Roubin E., Vienna, Austria.

Technical University in Eindhoven (July 1998). van Kasteren J. M. V, Eindhoven, the Netherlands.

TNO (February 1998). Institute of Industrial Technology, van Baarle, Delft, the Netherlands.

VACO (April 1998). Association for the Tyre and Wheel Business & Industry, Spuijbroek R., Leiden, the Netherlands.

Vrederstein (April 1998). Tyre manufacturer, Burlet R., Maastricht, the Netherlands.

VROM (March 1998). Ministry of Housing, Spatial Planning and the Environment, Dir. General for Environmental Protection, Brands H., The Hague, the Netherlands.

Appendix II. Tyre components

1. Tread
   material: rubber compound
   function: provide high wear resistance and good grip under all road conditions
2. Multi-ply belt
   material: steel cord or textile embedded in rubber compound
   function: enhances driving stability and gives the tyre its long service life
3. Casing
   material: steel and textile cord
   function: gives the tyre its structural strength and deflection characteristics
4. Inner lining
   material: rubber compound
   function: prevents diffusion of air and moisture in tubeless tyres
5. Sidewall
   material: rubber compound
   function: protects against weather effects
6. Bead reinforcement
   material: textile, steel cord
   function: reinforces the bead
7. Bead core
   material: steel or textile wire embedded in rubber compound
   function: fixes the tyre on the rim

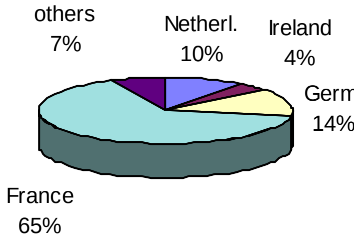
Appendix III. Calorific values of fuels and wastes

Material	*Calorific value in kJ/kg*
Waste sludge from the processing of petroleum	9 000
Brown coal	8 000 - 12 000
Waste and scrap of paper and paperboard	15 000
Waste of leather	16 000
Waste from production of paints and lacquers	17 000
Wood waste and scrap	19 000
Waste of polymers of vinyl chloride (PVC)	18 000 - 26 000
Waste of polyethylene terephthalate (PET)	23 000
Black coal	26 000 - 31 000
Used pneumatic tyres	30 000 - 35 000
Liquid fuels	42 000

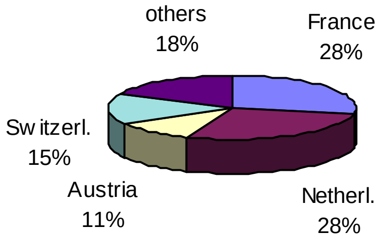
Source: Odpady, 1998; Barlaz, 1993

Appendix IV. Import of used tyres in EU in 1996

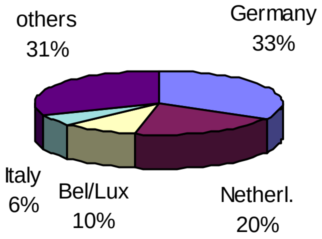
Import United Kingdom
51,600 tonnes



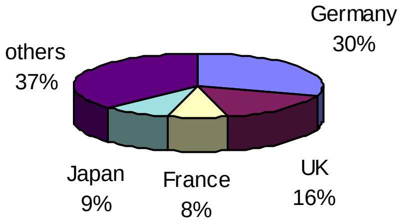
Import Germany
42,700 tonnes



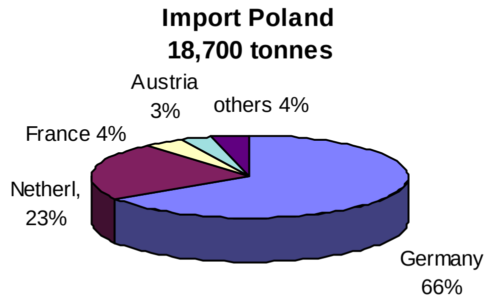
Import France
23,200 tonnes

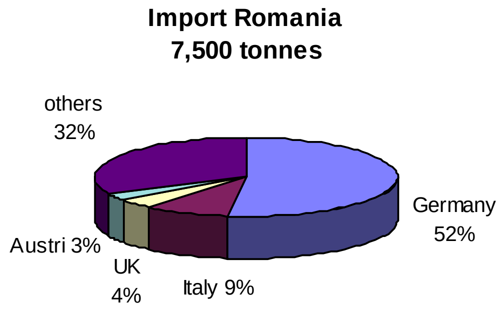


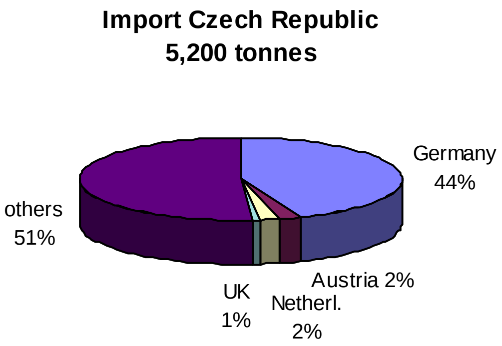
Import the Netherlands
18,900 tonnes

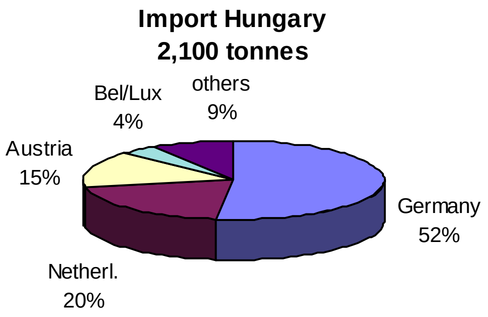


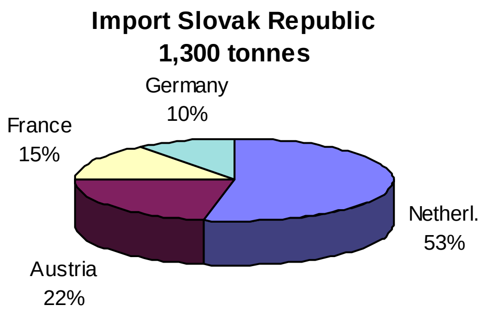
Appendix V. Imports of used tyres in EE in 1996



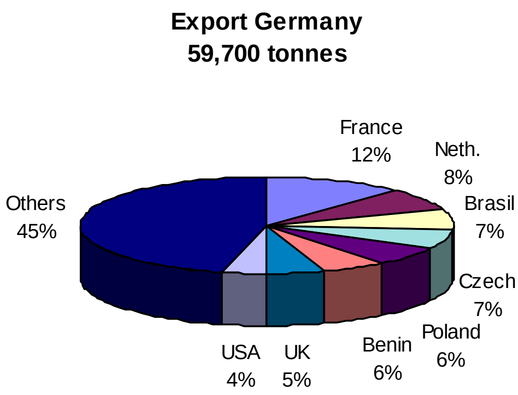


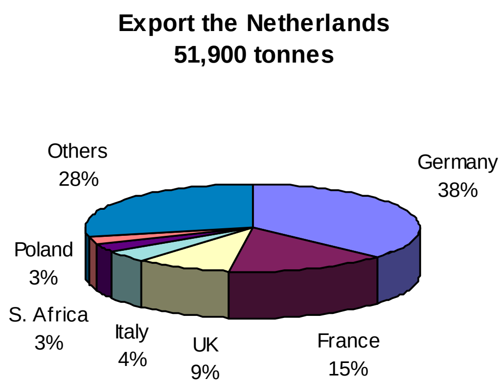


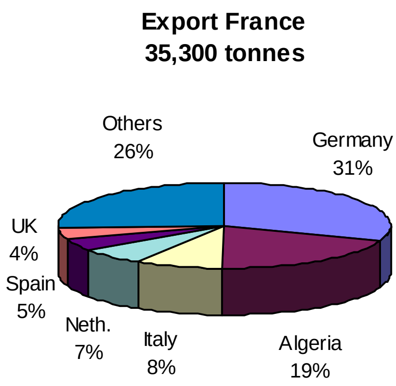


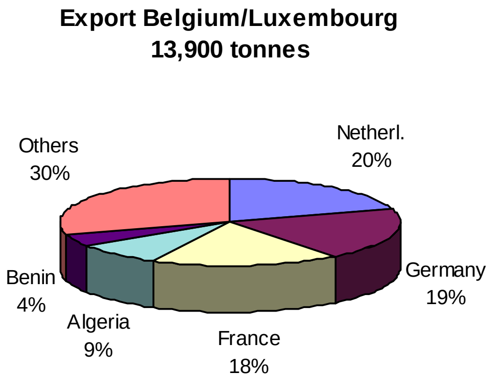


Appendix VI. Export of used tyres in EU in 1996

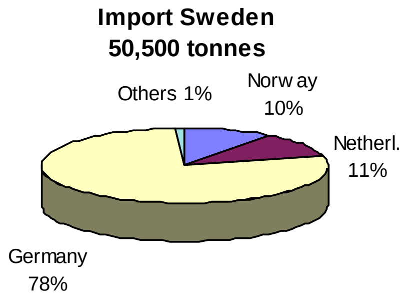


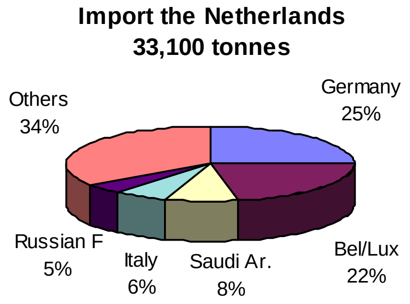


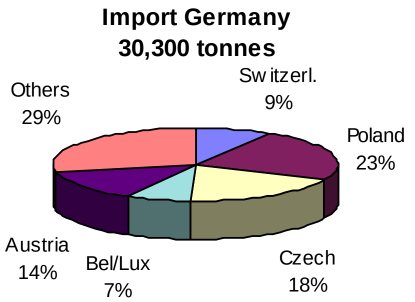


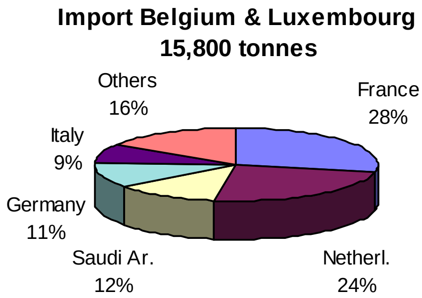


Appendix VII. Import of tyre related rubber waste in EU in 1996

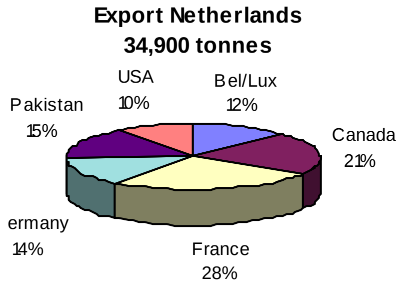


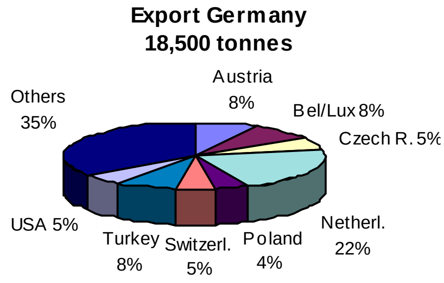


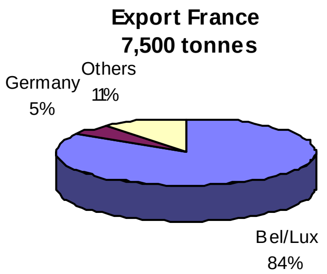


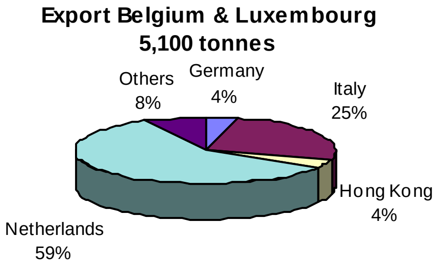


Appendix VIII. Export of tyre related rubber waste in EU in 1996









Appendix IX. Waste tyre management in 1991 and 1996

	France		Germany		Italy		United Kingdom	
Figures in %	1991	1996	1991	1996	1991	1996	1991	1996
Retreading	23	20	20	20	30	22	20	31
Material recovery	15	16	11	14	13	15	8	16
Energy recovery	3	15	37	45	6	23	20	27
Landfilling	59	45	32	21	51	40	52	26

Source: BLIC, 1997

Appendix X. Grinding companies in the Czech Republic

Company	Grinding technology	Annual capacity (tonnes)	Annual used capacity (tonnes)	Market
KAC Uherský Brod	mechanical	10 000	2 000	Eko-Rubber (reclaiming)
Recyklace Vřesová	mechanical	32 000	1 500	Kaučuk (tiles), Germany
Regutec Nemčičky	mechanical	not available	problems	road surface
Renogum Nilos	mechanical	200	200	road surface, Germany
Tubeco Rynholec	cryogenic	10 000	problems	not available
Sagan Králíky	cryogenic	10 000	1 500	Eko-Rubber (reclaiming)
Gumidom Ostrava	mechanical, shredding	not available	2 000	Eko-Rubber TDF

Source: Interviews, March 1998

Appendix XI. Trade pattern of the Czech Republic

Table XI. 1 Import and export of used tyres (HS 40122090) in tonnes

	Import 1993	1994	1995	1996	1997	Export 1993	1994	1995	1996	1997
Austria	534	562	740	240	378	614	80	11	1.5	<1
Belgium	30	20	13	5	0	0	1.2	18	0	0
Croatia	1.5	0	0	0	0	1.5	0	8	<1	0
Denmark	0	0	8	1.2	19	0	0	0	0	0
Estonia	0	0	<1	0	0	0	0	0	0	0
France	7	11	41	147	25	0	1.4	0	<1	0
Finland	0	0	0	0	0	0	0	0	0	0
Germany	6 770	6 070	7 377	4 630	6 463	336	1 090	1 486	143	21
Hungary	41	42	40	0	0	37	0	0	0	<1
Italy	26	16	<1	8	20	0	0	0	<1	<1
Netherlands	28	13	400	130	232	0	7.4	352	22	87
Poland	262	123	206	227	102	172	45	18	44	38
Russia	0	14	12	13	<1	376	9.4	<1	8	5
Slovenia	0	12	0	1.6	0	0	0	0	0	0
Slovakia	198	150	170	166	84	424	494	337	350	208
Spain	0	0	2	0	48	0	0	0	<1	0
Sweden	0	4	0	0	0	0	0	0	9.4	0
Switzerland	485	182	96	20	15	0	1.2	0	0	0
UK	<1	<1	0	24	60	0	0	0	0	<1
Ukraine	0	9	0	0	0	8.5	68	39	51	5
USA	0	28	<1	3	3	0	0	0	<1	<1
Other	<1	<1	2	618	2	20	<1	11	0	24
Total	8 393	7 261	9 111	6 249	7 968	1 436	1 799	2 280	641	389

Table XI.2 Import and export of rubber waste (HS 40040000) in tonnes

	Import 1993	1994	1995	1996	1997	Export 1993	1994	1995	1996	1997
Austria	0.8	0	1.28	0.003	0	17	1.5	0	0	0
Belgium	0	0	0	0	0	0	108	148	100	35
Croatia	0	0	0	0	0	1	380	0	0	10
France	0	0	0	0	0	631	554	89	0	0
Finland	0	0	0	6	0	0	0	0	0	0
Germany	261.2	70	268	2 575	5 048	3 250	3 350	2 581	4 113	4 411
Italy	0	43	0	11	0	0	0	0	0	0
Netherlands	145	0	45	21	0	592	318	187	98	140
Poland	0	38	0	0	0	1	0	0	21	1
Slovenia	0	132	82	70	80	2	132	82	0	0
Slovakia	702	628	1 398	1 604	1 851	200	67	4	47	41
Switzerland	0	2	3	33	2	0	0	0	0	0
UK	1.5	17	6	9	10	0	0	0	0	2
Ukraine	0	0	0	0	19	0	0	0	0	0
EU	0	0	0	0	22	0	0	0	0	0
Other	0	0	20	0	0	0	0	0	0	12.5
Total	1 228	932	1 824	4 311	7 080	4 694	4 533	3 093	4 397	4 653

Source: General Directorate of Customs of the Czech Republic, 1998

Appendix XII. Factor, input and output prices

	Item	*ECU*	*Unit*
Energy	electricity	0.100452	kWh
	gas	0.13698	m3
Labour	labour	22800	annual income
Inputs	tyres for hot retreading	660	tonne
	tyres for cold retreading	812	tonne
	tyres for recovery	52.8	tonne
	tread for hot retreading	1689	tonne
	tread for cold retreading	3561	tonne
	unvulcanised rubber	6027	tonne
	cement for cold retreading	1.4	litres
	cement for hot retreading	1.8	litres
	water	0.73	m^3
	nitrogen	110	tonne
Outputs	retreaded tyres (hot)	2300	tonne
	retreaded tyres (cold)	2537	tonne
	mechanical granulate	286	tonne
	cryogenic granulate	330	tonne
	steel	0	tonne
	oil	112	tonne
	carbon black	17	tonne
	coal	51	tonne
	reclaim	506	tonne

Appendix XIII. Avoided burdens

In order to conduct a consistent analysis, various assumptions which are explained below for individual processes were made.

Hot and cold retreading

Energy from primary production of tyres: According to Notarnicola (1998), the energy input for production of a new tyre is 848 000 MJ per tonne of tyres (23 556 kWh). Since casing comprises 80% of a tyre, the energy use for production of a casing is 18 844 kWh. Considering approximately 75% lower life span of a retreaded tyre compared to a new one, the energy savings from retreading a tyre represent 14 133 kWh per tonne of tyres. When "*hot retreading* production quaziefficiency" of 95.8% was taken into account, the considered avoided burdens were then 13 546 kWh per tonne of tyres. Production quaziefficiency was obtained as ratio of a number of retreaded tyres to a number of input tyres per year (22 400/23 370 = 95.8%). If for *cold retreading*, a "production quaziefficiency" of 97.5% was taken into account, the considered avoided burdens were then 13 780 kWh per tonne of tyres (16 080/16 490 = 97.5%).

Energy from rubber production: Rubber crumb from buffing is usually about 10% of the total tyre weight. Since crumb is a high quality rubber, it was included into avoided burdens as energy input for primary rubber production which is 30 680 MJ (8 522 kWh) per tonne of tyres (Notarnicola, 1998). Although Notarnicola considers passenger car tyres, the same data were used for truck tyres. The rubber content was assumed to be same for truck and car tyres (approximately 45% of tyre weight). Based on these assumptions, the energy saving from buffed rubber was considered to be 1 894 kWh per tonne of tyres.

Refused tyres: Tyres refused at the final inspection of retreading process have a potential for recycling. Since solid waste from retreading was not considered in this study, refused tyres were excluded from avoided burdens.

Mechanical and cryogenic grinding

Energy from rubber production: The energy usage for production of rubber contained in a new tyre is 8 522 kWh. The amount of rubber obtained during *mechanical grinding* represents 60% of tyre weight. Since granulate can replace low quality rubber, the 75% of energy savings were assumed. Based on these data, the avoided burdens were calculated as 2 557 kWh per tonne of tyres. During *cryogenic grinding* rubber recovered represents 65% of tyre weight. Assuming granulate can replace lower quality rubber, the avoided burdens of 2 770 kWh per tonne of tyres were considered which represent 75% of energy necessary for primary production.

Energy from steel production: The amount of steel obtained during mechanic and cryogenic grinding represents 25% of tyre weight. Avoided burdens of steel production were based on energy content of steel in a passenger car tyre which is 3 300 MJ considering the amount of steel 11% of tyre weight (Notarnicola, 1998). In case of truck tyre, the amount of steel is 25% of tyre weight, that is approximately two times more compared to a passenger car tyre.

Therefore, the related saved energy for truck tyre was calculated 6 600 MJ per tonne of tyres (1 830 kWh).

Reclaiming

Energy from rubber production: The energy use for production of total rubber, contained in a new tyre is 8 522 kWh. Since reclaim is of lower quality compared to new rubber, the energy savings were assumed as 75% of energy for rubber production. Based on these data, the avoided burdens were calculated as 6 392 kWh per tonne of tyres.

Pyrolysis

Energy from carbon production: In order to express avoided burdens related to the production of carbon black, the energy savings were expressed in terms of calorific values. For carbon black, the assumed energy savings equalled to be calorific value of coal which is 8 kWh per kilogram. The expected output of carbon black was 34% of the input tyre weight which means that 1 tonne of tyres equals 340 kg of carbon black. The saved energy was sum of energy obtained from 340 kg of carbon black which equals to 2 720 kWh per tonne of tyres.

Energy from oil production: The oil obtained from pyrolysis is usually used as a fuel; its calorific value is approximately 40 000 kJ per kilogram, e.g. 11.1 kWh per tonne. Depending on technology, the output of oil is about 51% of input tyre weight; that means from 1 tonne of tyres 510 kg of oil can be produced. Since a high sulphur content in obtained oil is expected (up to 1.5% according to the background literature, Cliff, 1995), the avoided burdens were assumed only as 75% of energy savings. Considering this assumption, the saved energy was calculated as 4 310 kWh per tonne of tyres.

Energy from steel production: The amount of steel obtained during pyrolysis is expected to be 13 % of tyre weight. Considering the same assumptions as for mechanical and cryogenic grindings, the related saved energy was calculated as 942 kWh per tonne of tyres.

Incineration in cement kilns

Energy from energy production: Avoided burdens are related to replacement of coal or other conventional fuels by waste tyres. One tonne of tyres, having the calorific value of 8 300 kWh, can supplement 1.04 tonnes of coal. The avoided burdens are then represented by saved energy of 8 632 kWh per tonne of tyres.

Energy from rubber production (for cement kiln only):* The cement kiln* is expected to incinerate tyres from which the tread rubber and the steel cord were removed and recycled. The avoided burdens were calculated based on the assumptions discussed under retreading. Based on these data, the considered energy savings related to the buffed crumb were 1 894 kWh per tonne of tyres.

Energy from steel production: The amount of steel obtained from removing the steel belt is expected to 50% of the total steel content in a tyre which is 25 % of tyre weight. Considering assumptions described under grinding, related saved energy was calculated as 915 kWh per tonne of tyres.

Appendix XIV. Cost benefit analysis (CBA)

Table XIV.1 Financial calculations of the CBA (v ECU per tonne of tyres)

	Category	Hot re-treading	Cold re-treading	Mechanical grinding	Cryogenic grinding	Reclaiming	Pyrolysis	Cement kiln	Cement kiln *
Inputs									
Fixed	investment	26,00	37,00	34,00	44,00	29,00	19,00	6,00	6,00
	maintainance	2,60	3,70	3,40	4,40	17,60	1,39	0	0
	operation	0	0	0	0	0	5,80	1,00	1,00
	transport	0	0	0	0	0	0	0	0
Energy	electricity	28,22	29,10	24,00	19,50	80,36	17,36	0	0
	gas	30,41	4,64	0	0	0	0	0	0
Labour	labour	216,80	307,42	60,80	60,80	11,08	17,10	3,51	3,51
Inputs	partly worn tyres	669,99	811,80	0	0	0	0	0	0
	worn out tyres	0	0	0	0	52,80	0	0	0
	tread	610,44	860,36	0	0	0	0	0	0
	unvulcanised rubber	0	128,67	0	0	0	0	0	0
	cement	11,29	11,13	0	0	0	0	0	0
	water	1,85	0	0	0	0,29	0	0	0
	nitrogen	0	0	0	82,50	0	0	0	0
	pyrolytic oils	0	0	0	0	0	0	0	0
	additives	0	0	0	0	1,76	0	0	0
Subtotal costs		***1597,59***	***2193,81***	***122,20***	***211,20***	***192,89***	***60,65***	***10,51***	***10,51***
Outputs									
	disposal fee	0	0	52,80	52,80	0	52,80	52,80	52,80
	tyres	2449,55	2750,08	0	0	0	0	0	0
	granulate	0	0	171,60	214,50	0	0	0	0
	rubber from buffing	5,27	5,28	0	0	0	0	0	0
	refused tyres	2,43	1,48	0	0	0	0	0	0
	reclaim	0	0	0	0	303,60	0	0	0
	steel	0	0	15,50	15,40	0	7,98	0	0
	textile	0	0	0	0	0	0	0	0
	gas	0	0	0	0	0	0	0	0
	oil	0	0	0	0	0	50,17	0	0
	carbon black	0	0	0	0	0	5,83	0	0
	energy	0	0	0	0	0	0	72.75	72.75
Subtotal revenues		***2457,24***	***2756,84***	***239,90***	***282,70***	***303,60***	***116,79***	***125,55***	***125,55***
Gross profit (excl. tax)		**859,65**	**563,04**	**117,70**	**71,50**	**110,71**	**3,34**	**115,04**	**115,04**

Appendix XV. Life cycle assessment (LCA)

Table XV.1 Inputs, outputs, direct emissions and transport emissions data

	Unit	Hot retread.	Cold retread.	Mechan. grinding	Cryog. grinding	Reclaim-ing	Pyrolysis	Cement kiln	Cement kiln*
Inputs									
partly worn tyres	tonne/year	1262	890	0	0	0	0	0	0
worn out tyres	tonne/year	0	0	7500	7500	10350	20000	13000	13000
tread	tonne/year	456	215	0	0	0	0	0	0
unvulcanized rubber	tonne/year	0	19	0	0	0	0		0
cement	liters	7800	7000	0	0	0	0	0	0
water	m3	3200	0	0	0	0	0	0	0
nitrogen	tonne/year	0	0	0	7500	0	0	0	0
pyrolytic oils	tonne/year	0	0	0	0	1242	0	0	0
additives	tonne/year	0	0	0	0	155	0	0	0
Outputs									
tyres	pieces/year	22400	16080	0	0	0	0	0	0
granulate	tonne/year	0	0	4500	4875	0	0	0	0
rubber from buffing	tonne/year	126	89	0	0	0	0	0	0
refused tyres	tonne/year	58	25	0	0	0	0	0	0
reclaim	tonne/year	0	0	0	0	6000	0	0	0
steel	tonne/year	0	0	1875	1875	0	2574	0	0
textile	tonne/year	0	0	1125	750	0	0	0	0
gas	tonne/year	0	0	0	0	0	490,6	0	0
oil	tonne/year	0	0	0	0	0	10345	0	0
carbon black	tonne/year	0	0	0	0	0	6864	0	0
Direct emissions									
CO_2	tonne/tontyre	0	0	0	0	0	4,42E-01	2,36E-03	2,36E-03
CO	tonne/tontyre	0	0	0	0	0	5,00E-04	1,22E-03	1,22E-03
SO_x	tonne/tontyre	0	0	0	0	0	1,50E-03	1,31E-03	1,31E-03
NO_x	tonne/tontyre	0	0	0	0	0	1,20E-03	8,55E-03	8,55E-03
HC	tonne/tontyre	1,91E-03	1,91E-03	0	0	3,05E-04	0	6,19E-04	6,19E-04
particulates	tonne/tontyre	2,30E-05	2,30E-05	4,60E-04	9,20E-04	0	1,50E-04	0	0
dust	tonne/tontyre	0	0	0	0	0	0	0	0
heavy metals	tonne/tontyre	0	0	0	0	0	0	0	0
solid waste	tonne/tontyre	0	0	0	0	6,00E-02	1,43E-04	0	0
aerosols	tonne/tontyre	0	0	0	0	0	0	0	0
VOC	tonne/tontyre	0	0	0	0	0	0	0	0
HCl	tonne/tontyre	0	0	0	0	0	0	0	0
dioxin	tonne/tontyre	0	0	0	0	0	0	0	0
Zn	tonne/tontyre	0	0	0	0	0	0	0	0
Transport emissions									
distance	km	1000	1000	1000	1000	1000	1000	1000	1000
diesel	liters	48,6	48,6	48,6	48,6	48,6	48,6	48,6	48,6
CO_2	tonne/tontyre	1,28E-01	1,28E-01	1,28E-01	1,28E-01	1,28E-01	1,28E-01	1,28E-01	1,28E-01
NO_x	tonne/tontyre	2,04E-03	2,04E-03	2,04E-03	2,04E-03	2,04E-03	2,04E-03	2,04E-03	2,04E-03
SO_2	tonne/tontyre	1,38E-04	1,38E-04	1,38E-04	1,38E-04	1,38E-04	1,38E-04	1,38E-04	1,38E-04
HC	tonne/tontyre	3,22E-04	3,22E-04	3,22E-04	3,22E-04	3,22E-04	3,22E-04	3,22E-04	3,22E-04
CO	tonne/tontyre	4,82E-04	4,82E-04	4,82E-04	4,82E-04	4,82E-04	4,82E-04	4,82E-04	4,82E-04
aerosols	tonne/tontyre	1,46E-04	1,46E-04	1,46E-04	1,46E-04	1,46E-04	1,46E-04	1,46E-04	1,46E-04

Table XV.2 Energy emissions, avoided burdens and total avoided burdens and emissions

	Unit	Hot retread.	Cold retread.	Mechan. grinding	Cryogen. grinding	Reclaim-ing	Pyrolysis	Cement kiln	Cement kiln*
Energy emissions									
electricity	KWh/tontyre	281	398	240	200	580	180	0	0
CO_2	tonne/tontyre	2,00E-01	2,83E-01	1,71E-01	1,42E-01	4,12E-01	1,28E-01	0	0
NO_x	tonne/tontyre	2,25E-04	3,18E-04	1,92E-04	1,60E-04	4,64E-04	1,44E-04	0	0
SO_2	tonne/tontyre	1,26E-04	1,79E-04	1,08E-04	9,00E-05	2,61E-04	8,10E-05	0	0
HC	tonne/tontyre	5,62E-06	7,96E-06	4,80E-06	4,00E-06	1,16E-05	3,60E-06	0	0
Hg	tonne/tontyre	7,87E-09	1,11E-08	6,72E-09	5,60E-09	1,62E-08	5,04E-09	0	0
CO	tonne/tontyre	6,85E-06	9,71E-06	5,86E-06	4,88E-06	1,41E-05	4,39E-06	0	0
solid waste	tonne/tontyre	2,79E-02	3,96E-02	2,39E-02	1,99E-02	5,76E-02	1,79E-02	0	0
Avoided burden									
steel production	kWh/tontyre	0	0	1830	1830	0	942	0	915
carbon	kWh/tontyre	0	0	0	0	0	2720	0	0
oil	kWh/tontyre	0	0	0	0	0	4310	0	0
rubber production	kWh/tontyre	1894	1894	3835	4155	6392	0	0	1894
energy consumption	kWh/tontyre	0	0	0	0	0	0	8632	8632
tyre production	kWh/tontyre	13540	13780	0	0	0	0	0	0
Total avoided burden									
CO_2	tonne/tontyre	2,84E-02	4,01E-02	4,82E-04	7,50E03	4,82E-04	4,91E02	1,79E-03	1,79E-03
NO_x	tonne/tontyre	1,46E-04	1,46E-04	1,46E-04	1,46E-04	1,24E03	1,03E04	8,70E-03	8,70E-03
SO_2	tonne/tontyre	1,91E-03	1,91E-03	0	0	1,55E02	6,86E03	6,19E-04	6,19E-04
HC	tonne/tontyre	2,81E02	3,98E02	2,40E02	2,00E02	6,58E03	1,80E02	0	0
Hg	tonne/tontyre	2,34E04	1,71E04	1,00E03	1,00E03	1,00E03	1,00E03	1,00E03	1,00E03
CO	tonne/tontyre	1,94E03	1,94E03	4,55E03	4,92E03	4,86E01	4,86E01	4,86E01	4,86E01
solid waste industrial	tonne/tontyre	1,26E02	8,92E01	1,28E-01	1,28E-01	1,88E-01	1,28E-01	1,28E-01	1,28E-01
Total emissions									
CO_2	tonne/tontyre	2,00E-01	2,83E-01	1,71E-01	1,42E-01	4,12E-01	5,70E-01	2,36E-03	2,36E-03
CO	tonne/tontyre	6,85E-06	9,71E-06	5,86E-06	4,88E-06	1,41E-05	5,04E-04	1,22E-03	1,22E-03
SO_x	tonne/tontyre	1,26E-04	1,79E-04	1,08E-04	9,00E-05	2,61E-04	1,58E-03	1,31E-03	1,31E-03
NO_x	tonne/tontyre	2,25E-04	3,18E-04	1,92E-04	1,60E-04	4,64E-04	1,34E-03	8,55E-03	8,55E-03
HC	tonne/tontyre	1,91E-03	1,91E-03	4,80E-06	4,00E-06	3,16E-04	3,60E-06	6,19E-04	6,19E-04
particulates	tonne/tontyre	2,30E-05	2,30E-05	4,60E-04	9,20E-04	0	1,50E-04	0	0
dust	tonne/tontyre	0	0	0	0	0	0	0	0
heavy metals	tonne/tontyre	0	0	0	0	0	0	0	0
solid waste	tonne/tontyre	2,79E-02	3,96E-02	2,39E-02	1,99E-02	1,18E-01	1,80E-02	0	0
aerosols	tonne/tontyre	0	0	0	0	0	0	0	0
VOC	tonne/tontyre	0	0	0	0	0	0	0	0
HCl	tonne/tontyre	0	0	0	0	0	0	0	0
dioxin	tonne/tontyre	0	0	0	0	0	0	0	0
Zn	tonne/tontyre	0	0	0	0	0	0	0	0
Hg	tonne/tontyre	7,87E-09	1,11E-08	6,72E-09	5,60E-09	1,62E-08	5,04E-09	0	0

Appendix XVI. Economic valuation (EVA)

Table XVI.1 Economic valuation of process and related avoided burdens

	Price	Hot re-treading	Cold re-treading	Mech. grinding	Cryogenic grinding	Re-claiming	Pyrolysis	Cement kiln	Cement kiln*
Process									
Global warming									
CO_2	5,1	1,02E+00	1,44E+00	8,71E-01	7,25E-01	2,10E+00	2,90E+00	1,21E-02	1,21E-02
Human health									
NO_x nitrate	718	1,61E-01	2,29E-01	1,38E-01	1,15E-01	3,33E-01	9,65E-01	6,14E+00	6,14E+00
NO_x ozone	18000	4,05E+00	5,73E+00	3,46E+00	2,88E+00	8,35E+00	2,42E+01	1,54E+02	1,54E+02
SO_2 direct	629	7,95E-02	1,13E-01	6,79E-02	5,66E-02	1,64E-01	9,94E-01	8,23E-01	8,23E-01
SO_2 indirect	6953	8,79E-01	1,25E+00	7,51E-01	6,26E-01	1,81E+00	1,10E+01	9,10E+00	9,10E+00
particlates	18000	4,14E-01	4,14E-01	8,28E+00	1,66E+01	0	2,70E+00	0	0
VOC	602	0	0	0	0	0	0	0	0
heavy metal	15000	1,18E-04	1,67E-04	1,01E-04	8,40E-05	2,43E-04	7,56E-05	0	0
Zn	15	0	0	0	0	0	0	0	0
aerosols	0	0	0	0	0	0	0	0	0
HCl	0	0	0	0	0	0	0	0	0
dioxin	0	0	0	0	0	0	0	0	0
HC	602	1,15E+00	1,15E+00	2,89E-03	2,41E-03	1,90E-01	2,17E-03	3,73E-01	3,73E-01
solid waste to collec-tors	2,12	5,92E-02	8,39E-02	5,06E-02	4,22E-02	2,49E-01	3,82E-02	0	0
Disamenity									
solid waste	5	1,40E-01	1,98E-01	1,19E-01	9,94E-02	5,88E-01	9,02E-02	0	0
Natural resources									
SO_2 damage to forests	1,25	1,58E-04	2,24E-04	1,35E-04	1,13E-04	3,26E-04	1,98E-03	1,64E-03	1,64E-03
SO_2 damage agricul-ture	8,27	1,05E-03	1,48E-03	8,93E-04	7,44E-04	2,16E-03	1,31E-02	1,08E-02	1,08E-02
SO_2 damage to lakes	1,45	1,83E-04	2,60E-04	1,57E-04	1,31E-04	3,78E-04	2,29E-03	1,90E-03	1,90E-03
Buildings									
dust and particulates	300	6,90E-03	6,90E-03	1,38E-01	2,76E-01	0	4,50E-02	0	0
SO_2	260	3,29E-02	4,66E-02	2,81E-02	2,34E-02	6,78E-02	4,11E-01	3,40E-01	3,40E-01
Subtotal process		***7,99***	***10,67***	***13,90***	***21,41***	***13,86***	***43,35***	***170,78***	***170,78***
Avoided burden									
Global warming									
CO_2	5,1	-5,60E01	-5,69E01	-2,06E01	-2,17E01	-2,32E01	-2,89E01	-3,13E01	-4,15E01
Human health									
NO_x nitrate	718	-8,87E00	-9,00E00	-3,25E00	-3,44E00	-3,67E00	-4,58E00	-4,96E00	-6,57E00
NO_x ozone	18000	-2,22E02	-2,26E02	-8,16E01	-8,62E01	-9,20E01	-1,15E02	-1,24E02	-1,65E02
SO_2 direct	629	-4,37E00	-4,44E00	-1,60E00	-1,69E00	-1,81E00	-2,26E00	-2,44E00	-3,24E00
SO_2 indirect	6953	-4,83E01	-4,90E01	-1,77E01	-1,87E01	-2,00E01	-2,49E01	-2,70E01	-3,58E01
Hg	15000	-6,48E-03	-6,58E-03	-2,38E-03	-2,51E-03	-2,68E-03	-3,35E-03	-3,63E-03	-4,81E-03
HC	602	-1,86E-01	-1,89E-01	-6,82E-02	-7,21E-02	-7,70E-02	-9,60E-02	-1,04E-01	-1,38E-01
solid waste to collec-tors	2,12	-3,25E+00	-3,30E+00	-1,19E+00	-1,26E+00	-1,35E+00	-1,68E+00	-1,82E+00	-2,41E+00
Disamenity									
solid waste	5	-7,67E+00	-7,79E+00	-2,82E+00	-2,98E+00	-3,18E+00	-3,96E+00	-4,29E+00	-5,69E+00
Natural resources									
SO_2 damage to forests	1,25	-8,68E-03	-8,82E-03	-3,19E-03	-3,37E-03	-3,60E-03	-4,48E-03	-4,86E-03	-6,44E-03
SO_2 damage agricul-ture	8,27	-5,74E-02	-5,83E-02	-2,11E-02	-2,23E-02	-2,38E-02	-2,97E-02	-3,21E-02	-4,26E-02
SO_2 damage to lakes	1,45	-1,01E-02	-1,02E-02	-3,70E-03	-3,91E-03	-4,17E-03	-5,20E-03	-5,63E-03	-7,47E-03
Buildings									
SO_2	260	-1,81E+00	-1,83E+00	-6,63E-01	-7,00E-01	-7,48E-01	-9,33E-01	-1,01E+00	-1,34E+00
Subtotal av. burdens		***-352,75***	***-358,24***	***-129,49***	***-136,79***	***-146,09***	***-182,21***	***-197,29***	***-261,49***

Table XVI.2 Economic valuation of transport emissions and the total external costs

	Price	Hot re-treading	Cold re-treading	Mech. grinding	Cryogenic grinding	Re-claiming	Pyrolysis	Cement kiln	Cement kiln*
Transport									
Global warming									
CO_2	5,1	6,52E-01	6,52E-01	6,52E-01	6,52E-01	6,52E-01	6,52E-01	6,52E-01	6,52E-01
Human health									
CO direct	21	4,29E-02	4,29E-02	4,29E-02	4,29E-02	4,29E-02	4,29E-02	4,29E-02	4,29E-02
SO_2 direct	2500	3,45E-01	3,45E-01	3,45E-01	3,45E-01	3,45E-01	3,45E-01	3,45E-01	3,45E-01
CO indirect	0,045	2,17E-05	2,17E-05	2,17E-05	2,17E-05	2,17E-05	2,17E-05	2,17E-05	2,17E-05
NO_x indirect	4700	9,61E+00	9,61E+00	9,61E+00	9,61E+00	9,61E+00	9,61E+00	9,61E+00	9,61E+00
Agriculture									
SO_2	6,9	9,52E-04	9,52E-04	9,52E-04	9,52E-04	9,52E-04	9,52E-04	9,52E-04	9,52E-04
NO_x	200	4,09E-01	4,09E-01	4,09E-01	4,09E-01	4,09E-01	4,09E-01	4,09E-01	4,09E-01
Subtotal transport		***11,06***	***11,06***	***11,06***	***11,06***	***11,06***	***11,06***	***11,06***	***11,06***
Total categories									
Global warming		-54,313	-54,759	-19,028	-20,332	-20,430	-25,362	-30,648	-40,837
Human health		-270,428	-272,718	-82,688	-81,100	-97,853	-98,481	19,768	-32,503
Natural resources		0,335	0,334	0,383	0,381	0,381	0,388	0,381	0,368
Buildings		-1,766	-1,780	-0,497	-0,401	-0,680	-0,477	-0,670	-0,998
Disamenity		-7,533	-7,594	-2,697	-2,876	-2,589	-3,873	-4,291	-5,688
Total		**-333,71**	**-336,52**	**-104,53**	**-104,33**	**-121,17**	**-127,80**	**-15,46**	**-79,66**
Total external costs and benefits									
Process		7,99	10,67	13,90	21,41	13,86	43,35	170,78	170,78
Transport		11,06	11,06	11,06	11,06	11,06	11,06	11,06	11,06
Avoided burden		-352,75	-358,24	-129,49	-136,79	-146,09	-182,21	-197,29	-261,49
Total external net benefit		**-333,71**	**-336,52**	**-104,53**	**-104,33**	**-121,17**	**-127,80**	**-15,46**	**-79,66**

Appendix XVII. List of abbreviations

Abbreviation	Explanation
ARN	Auto Recycling Netherlands
BEM	Tyre and Environment
BIR	Bureau of International Recycling
BLIC	Bureau des Liasons Industries de Caoutchouc
CIS	Commonwealth of Independent States
CBA	Cost Benefit Analysis
CBS	The Dutch Central Bureau of Statistics
COMTRADE	International Commerce Database
DG III	Directorate General III on Industry of the European Commission
DG XI	Directorate General XI on Environment, Nuclear Safety and Civil Protection of the European Commission
5EAP	5th Environmental Action Programme
ECU	European Currency Union
EEA	European Environmental Agency
EEC	European Economic Community
EFTA	European Free Trade Association
EPA	Environmental Protection Agency
ETRA	European Tyre Recycling Association
EU	European Union
HC	Hydrocarbons
EVA	Economic Valuation
HS	Harmonised Commodity Description and Coding System
IVM	Institute for Environmental Studies (Free University, Amsterdam)
IRSG	International Rubber Study Group
LCA	Life Cycle Assessment
NGO	Non Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
RAPRA	Rubber and Plastic Recycling Association
TDF	Tyre Derived Fuel
TNO	Institute for Industrial Technology
TRAINS	Trade Analysis and Information System
TWG	Technical Working Group
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environmental Programme
VOC	Volatile Organic Compounds
VACO	The Dutch Association for the Tyre, Wheel Business and Industry
VROM	Ministry of Spatial Planning, Housing and Environment